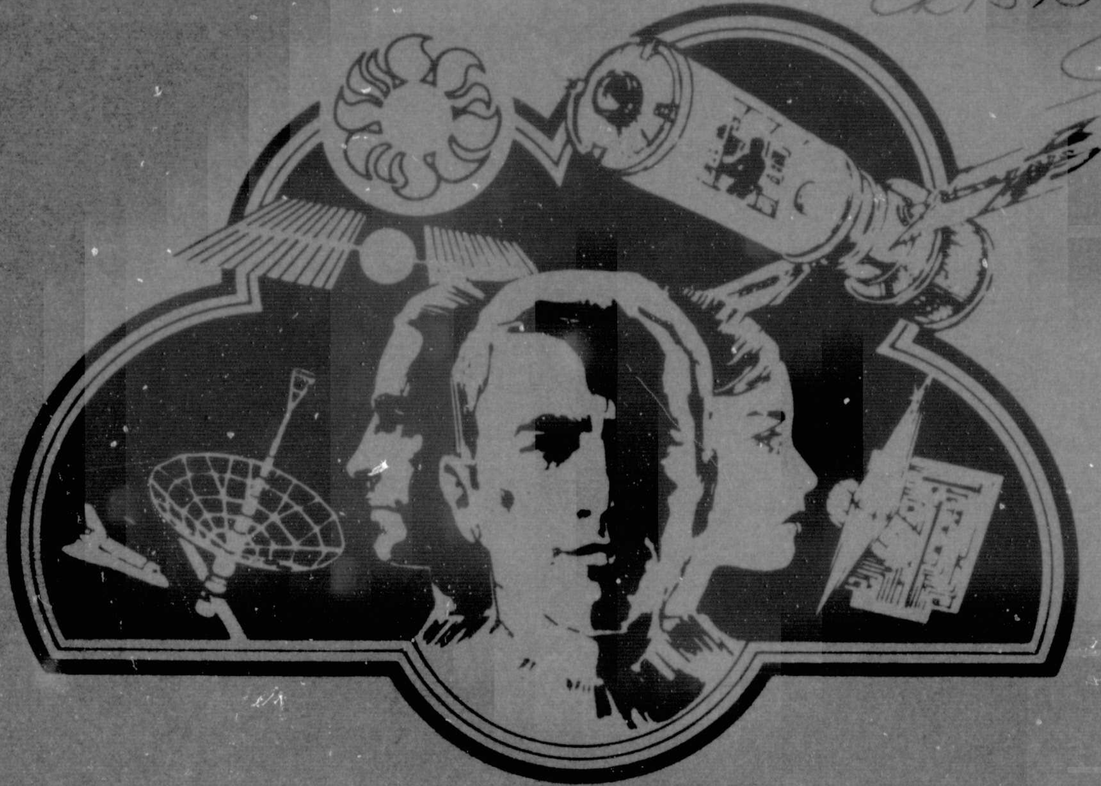
JULY 1977

MDC G6922

CR151521



SPACE STATION SYSTEMS ANALYSIS STUDY
PART 3: DOCUMENTATION

VOLUME 4
Supporting Research and Technology Report

(NASA-CR-151521) SPACE STATION SYSTEMS ANALYSIS STUDY. PART 3: DOCUMENTATION. VOLUME 4: SUPPORTING RESEARCH AND TECHNOLOGY REPORT (McDonnell-Douglas Astronautics Co.) 81 p HC A05/MF A01

N77-33238

Unclas
G3/15 51038

CONTRACT NO. NAS 9-14958
DPD NO. 524
DR NO. MA-04

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS
CORPORATION

MCDONNELL DOUGLAS

SPACE STATION SYSTEMS ANALYSIS STUDY

PART 3: DOCUMENTATION

VOLUME 4
Supporting Research and Technology Report

JULY 1977

MDC G6922

CONTRACT NO. NAS 9-14958
DPD NO. 524
DR NO. MA-04

APPROVED BY: C J DaRos

C. J. DaROS
STUDY MANAGER, SPACE STATION STUDY

PREPARED FOR: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

5301 Bolsa Avenue, Huntington Beach, CA 92647

PREFACE

The Space Station Systems Analysis Study is a 15-month effort (April 1976 to June 1977) to identify cost-effective Space Station systems options for a manned space facility capable of orderly growth with regard to both function and orbit location. The study activity has been organized into three parts. Part 1 was a 5-month effort to review candidate objectives, define implementation requirements, and evaluate potential program options in low earth orbit and in geosynchronous orbit. Part 2 was also a five-month effort to define and evaluate specific system options within the framework of the potential program options developed in Part 1.

Part 3, the last portion of this study, defines a series of program alternatives and refines associated system design concepts so that they satisfy the requirements of the low earth orbit program option in the most cost-effective manner.

The final reporting of the Part 3 study activity consists of the following·

- Volume 1, Executive Summary
- Volume 2, Technical Report
- Volume 3, Appendixes
  - Book 1, Supporting Data
  - Book 2, Supporting Data
- Volume 4, Supporting Research and Technology Report
- Volume 5, Cost and Schedules Data

A complete list of Parts 1 and 2 tables of contents are included for references in Volume 3, Book 2 in Section 17 of the appendix.

During this study, subcontract support was provided to the McDonnell Douglas Astronautics Company (MDAC) by TRW Systems Group, Aeronutronic Ford Corporation, the Raytheon Company, and Hamilton Standard.

Questions regarding the study activity or the material appearing in this report should be directed to:

Jerry W. Craig, EA 4
Manager, Space Station Systems Analysis Study
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 70058

or

C. J. DaRos
Study Manager, Space Station Systems Analysis Study
McDonnell Douglas Astronautics Company-West
Huntington Beach, California 92647
Telephone (714) 896-1885

CONTENTS

SECTION 1
INTRODUCTION

A primary conclusion of the Space Station Systems Analysis Study (SSSAS) is that the design and operational requirements of the program which would evolve a Space Construction Base (SCB) are comfortably within the state-of-the-art. However, several system and technology issues remain to be examined before a commitment is made to Phase C/D for the first SCB elements. These issues range from extended examination of system alternatives to the analysis of potential means of electrical energy storage. A number of issues involve the development of improved methods or models for the analysis of operational requirements or the prediction of system performance.

Six additional issues have been identified for examination in the area of "applications" or missions. Two of these represent an extension of the state-of-the-art in the sense that the required sizes of the mission hardware represent major increases over previous developments. The implications of the associated scaling problems require more detailed analysis than has been possible to date.

This Supporting Research and Technology (SRT) Report provides a brief description of each of the recommended SRT items resulting from the SSSAS. These descriptions include (A) the title, (B) the status with respect to the state-of-the-art, (C) the justification, (D) the technical plan including objectives and technical approach, (E) resource requirements categorized by manpower, specialized facilities, and funding in 1977 dollars, and (F) the target schedule.

The objective of the SRT is to provide high confidence in the solutions for the various functional system developmental problems, and to do so within a time period compatible with the overall evolutionary SCB schedule. The SRT appears feasible both from technical and schedule standpoints but is subject to review with respect to funding.

Section 2
SUMMARY

Review of the SRT items recommended in this report shows, as graphically displayed in Figure 2-1, that the predominant milestone for SRT completion is the Phase C/D ATP for the Space Construction Module. The current baseline date is October 1979. As shown in Table 2-1, the SRT identified herein is estimated to require $22.2 million in 1977 dollars. Of that total, approximately $12.3 million or 56 percent is required for items which should be completed before October 1979 for a minimum risk SCB program.

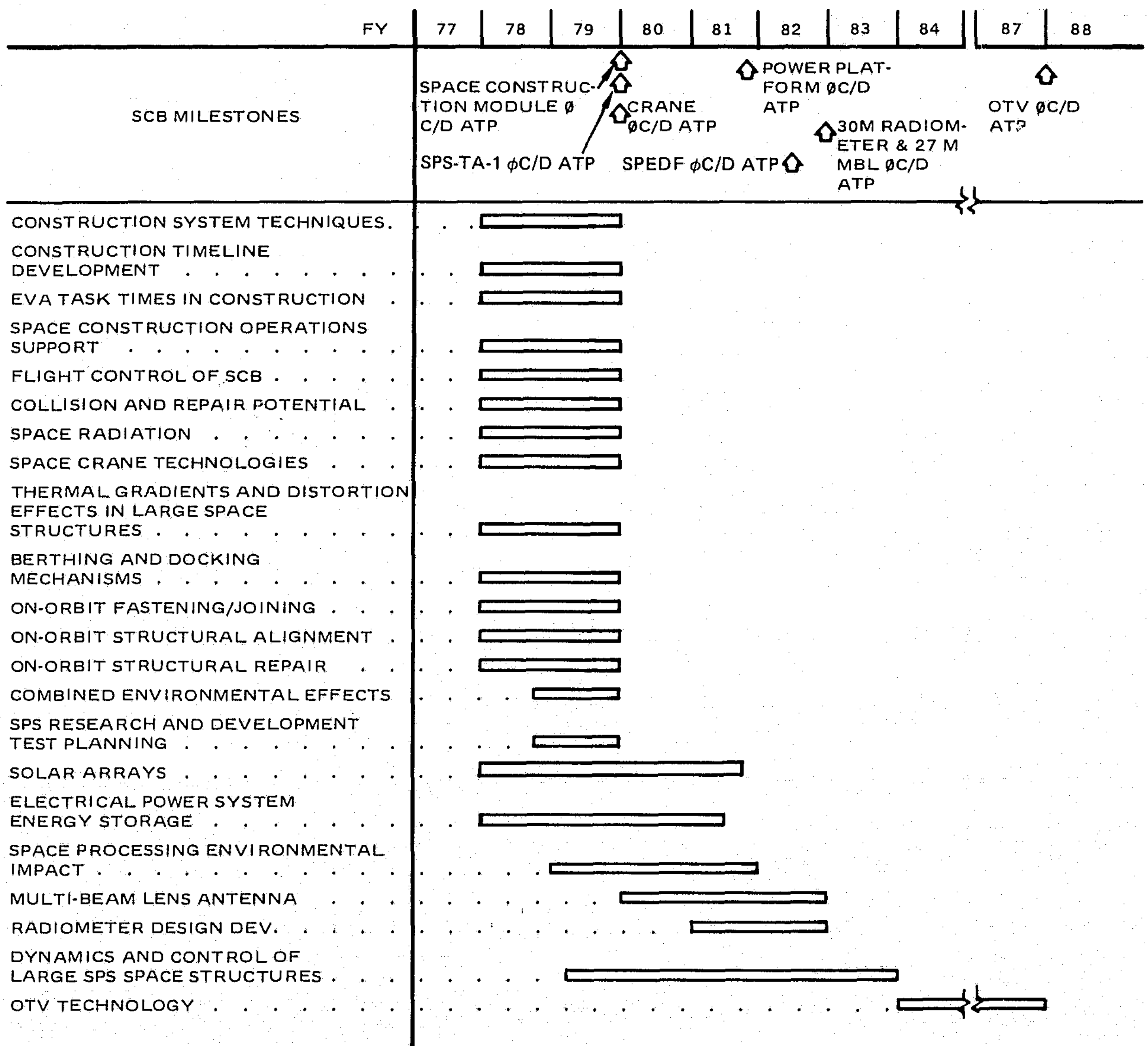


Figure 2-1. Supporting Research and Technology Summary Schedule

Table 2-1

SUPPORTING RESEARCH AND TECHNOLOGY RESOURCES SUMMARY

Category and Title	Requirement (Total man-years)	Specialized Facilities Required?	Funding Requirements (thousands of 1977 dollars)
SPACE SYSTEM STUDIES			
Construction System Techniques	12	No	960
Construction Timeline Development	12	No	960
EVA Task Times in Construction	12	Yes	1,230
Space Construction Operations Support Requirements	10	No	800
Combined Environmental Effects on Space Structures	4	No	320
Berthing and Docking Mechanisms	6	No	500
Flight Control of the SCB	7	No	600
Collision and Repair Potential	5	Yes	410
Engine Exhaust Plume Induced Effects	4	No	336
Space Radiation	4	Yes	320
SPACE SYSTEMS TECHNOLOGY PROGRAMS			
Space Crane Technologies	37	No	3,020
On-orbit Fastening and Joining	8	Yes	760
On-orbit Structural Alignment	11	No	980
On-orbit Structural Repair	5	Yes	425
Solar Arrays	12	No	1,210

Table 2-1

SUPPORTING RESEARCH AND TECHNOLOGY RESOURCES SUMMARY (Continued)

Category and Title	Requirement (Total man-years)	Specialized Facilities Required?	Funding Requirements (thousands of 1977 dollars)
Electrical Power System Energy Storage	20	No	1,905
OTV (Orbit Transfer Vehicle) Technology	5	No	400
APPLICATIONS			
SPS Research and Development Test Planning	5	No	400
Thermal Gradients and Distortion Effects in Large Space Structures	3	No	240
Dynamics and Control of Large SPS Space Structures	38	No	3, 310
Radiometer Design Development	8	No	760
Multi-beam Lens Antenna	14	Yes	1, 240
Space Processing Environmental Impacts	10	No	830
			21,916

The balance of the items are keyed to Phase C/D ATP milestones for the Power Module (Oct 78), Power Platform (Jul 81), SPS-TA-1 (Oct 79), Radiometer (Oct 82), Multi-beam Lens Antenna (Oct 82), Space Processing Engineering Development Facility (SPEDF) (Jan 82), or the Orbit Transfer Vehicle (OTV) (Oct 87).

It should be made clear that the achievement of a January 1984 IOC for the Space Construction Module is predicated on accomplishing each of the SRT items within its indicated time frame. In the event that these SRT items are not accomplished, or if they are achieved outside their allocated time frames, the probability of achieving the program milestones is diminished.

SECTION 3
SUPPORTING RESEARCH AND TECHNOLOGY ITEMS

The twenty-three SRT items defined in this section comprise the principal R&T efforts identified in the SSSAS study to be prerequisite to Phase C/D for the elements of the Space Construction Base. Each item has been identified with a specific SCB element. The schedule presented for each SRT item is keyed to the SCB element development milestone at which the R&T results are required. In most cases, that milestone is the Space Construction Module Phase C/D ATP.

The SRT items have been categorized as (1) Space System Studies, which include SCB-level R&T and studies of broad applicability, (2) Space Systems Technology Programs, which involve studies of system- or lower-level phenomena and design approaches, or (3) Applications, under which objective element and mission R&T are described.

It has been assumed that none of the SRT tasks could begin prior to fiscal 1978. Consequently, several of the items are considered to be candidates for inclusion in a Phase B follow-on to the SSSAS.

3.1 SPACE SYSTEM STUDIES

The SRT items in this category would pursue investigation of specific questions related to the development and operation of the overall Space Construction Base. These studies generally deal with phenomena at the SCB system level; however most of these items will provide information which has application to any large, long-duration space system.

The items included in this category are as follows:

- Construction System Techniques
- Construction Timeline Development
- EVA Task Times in Construction
- Space Construction Operations Support Requirements
- Combined Environmental Effects on Space Structures
- Berthing and Docking Mechanisms
- Flight Control of the SCB
- Collision and Repair Potential
- Engine Exhaust Plume Induced Effects
- Space Radiation

A. Title: CONSTRUCTION SYSTEM TECHNIQUES

B. Status: Recent system and technology studies have indicated a multitude of construction techniques which could be used in conjunction with Shuttle sortie, Shuttle-tended, or continuously manned Space Station missions to build various types of space structures. These construction techniques include deployable structures, assemble-in-orbit type structures, and those which may require fabrication and assembly in orbit. The SSSAS studies funded by JSC and MSFC, as well as the OCDA and OCSE studies, have made significant in-roads in illustrating and comparing various construction techniques and the evolution of those techniques as space construction progresses in time.

C. Justification: Many of the construction techniques postulated thus far possess high commonality of application from one structure to another; others, by necessity, are specialized due to the type of structure being built. A concentrated technology effort is needed to objectively summarize, categorize, and quantitatively evaluate existing documented techniques and to compare and recommend those construction techniques which merit further detailed study. This evaluation would be based on a priori ranking criteria and would take into account the three evolutionary phases of large space structures (LSS) missions discussed below.

D. Technical Plan:

(1) Objectives

The objectives of this SRT item would be to systematically analyze all existing documented construction techniques for large space structures, supplement that data with any necessary sizing, production rates, costs, etc., in order to make valid comparisons, and to quantitatively evaluate the techniques based on three time frames in the evolution of space construction: (1) Shuttle sorties, (2) Shuttle-tended; and (3) continuously manned space station missions. Suggested modifications to existing techniques and additional techniques worthy of future study would be delineated.

(2) Technical Approach

(a) Compile all construction system information from recent (1970 to present) LSS system and technology studies. Define ranking criteria for the three system time frames.

(b) Categorize construction techniques according to the manner in which the structure is built and the type of structure. Assess worthiness of commonality of technique for several different structures versus specialized techniques for each structure. Supplement quantitative data when necessary. Rank techniques.

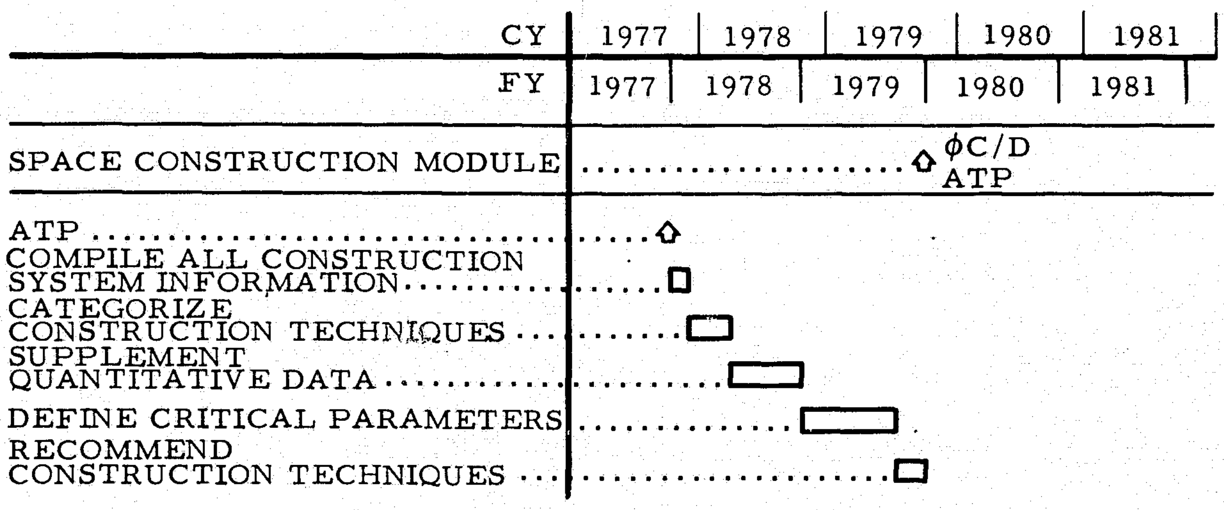
(c) Summarize and discuss evaluations and rankings. Define critical parameters which require further study, either analytically or experimentally, in order to substantiate rankings. Recommend other construction techniques for future study.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	6	6	12
(2) Specialized Facilities		none required	
(3) Funding			
• direct labor	$480K	$480K	$960K

F. Target Schedule:

CR60



A. Title: CONSTRUCTION TIMELINE DEVELOPMENT

B. Status: Several current studies have produced estimated timelines for on-orbit construction of large hardware items. These times have not been validated by either detailed analysis or test.

C. Justification: The timelines for construction produced by various investigators have revealed widely varying time estimates for construction of similar items. Since the capability of the Shuttle to support on-orbit construction is highly dependent on the time required, it is necessary to more precisely establish process times. The work of this SRT item parallels the development of EVA task times suggested as a separate SRT item.

D. Technical Plan:

(1) Objective

This SRT is intended to establish methodology which will allow accurate estimation of total construction process times.

(2) Technical Approach

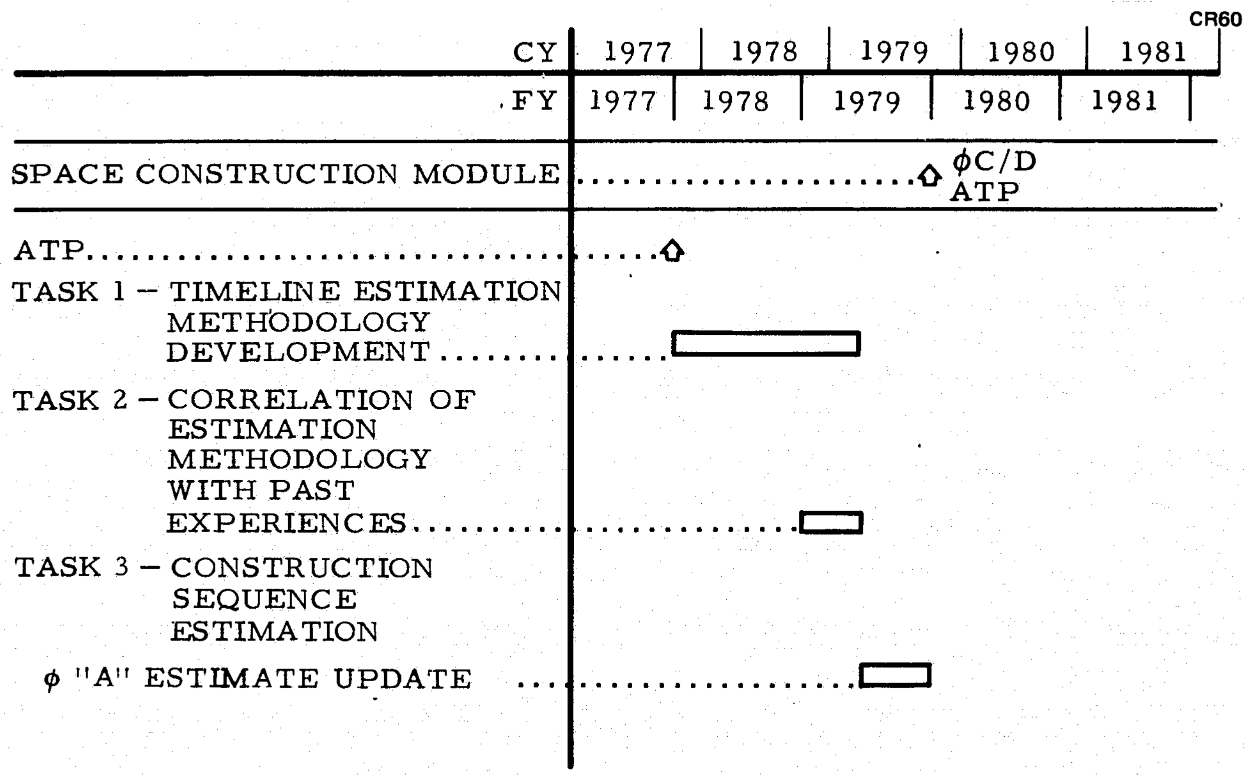
Task 1 will review construction sequences from such studies as the Space Station Systems Analysis Study and identify types of tasks involved. These will be separated into three preliminary categories: (1) those which are subject to technical analysis (e.g., translation of parts by a crane), (2) those which require estimates of EVA performance (see SRT Item "EVA Task Times in Construction,") and (3) those for which time estimates are highly dependent on design (e.g., mechnical alignment.) Methodology for estimating times for completion of these types of tasks, for developing criteria for designing to minimize time, and/or to make it more predictable will be established. Task 2 will evaluate past construction experience and develop time estimation factors for various types of processes to account for learning and to provide for contingencies. These will be used to validate or adjust the results of

Task 1. Task 3 will use the methodology developed to re-estimate the time for the construction sequences identified in Task 1.

E. Resource Requirements:

	FY 77	FY 78	FY 79	Totals
(1) Manpower (man-yr)	3	6	3	12
(2) Specialized Facilities		none required		
(3) Funding				
• Direct labor	$240K	$480K	$240K	$960K

F. Target Schedule:



A. Title: EVA TASK TIMES IN CONSTRUCTION

B. Status: The capability of man to successfully perform tasks in an EVA situation has been demonstrated. It is now necessary to investigate what man's productivity will be and what aids he will need in construction situations to maximize his effectiveness.

C. Justification: The Space Station Systems Analysis Study (SSSAS) has determined that significant EVA effort is required for on-orbit construction of large structures. In the cases studied, over 50% of the manhours expended in construction were spent in EVA. Because of this, the estimates of how long it takes to construct various items on-orbit are very sensitive to current evaluations of man's EVA capability. Since the construction system techniques and construction aids provided man can materially affect his productivity, parallel consideration must be given to the types of aids to be provided.

D. Technical Plan:

(1) Objectives

The primary objective is to develop improved methods for estimating the time it takes man to perform construction tasks in an EVA mode. A secondary objective is to determine EVA aids which will help minimize the time required and/or make the tasks easier.

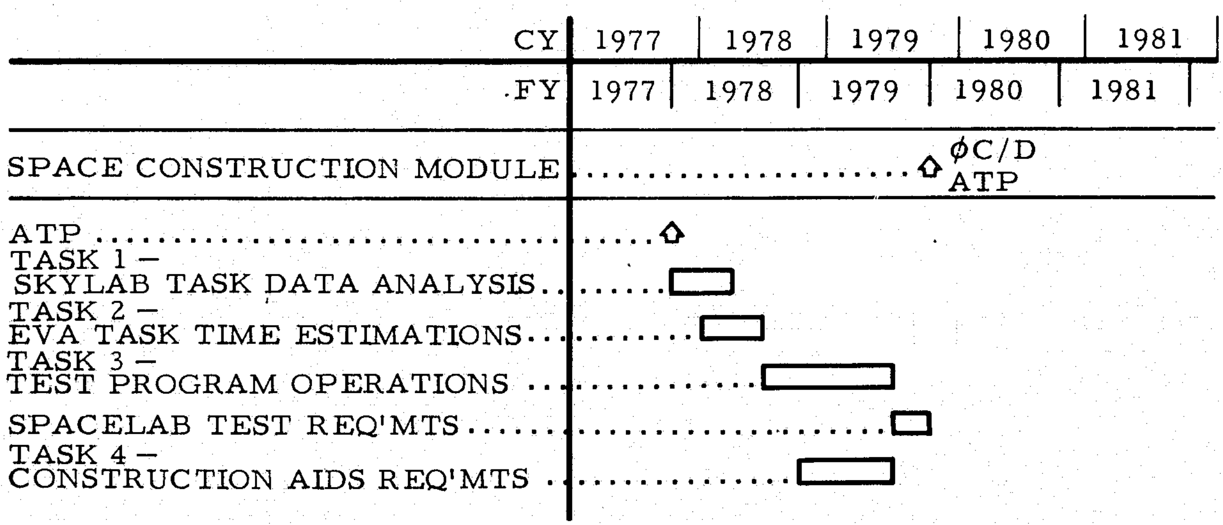
(2) Technical Approach

Task 1 is to review task data from Skylab in which over 500 man-days of combined spaceflight were accumulated. Analysis of task performance data from Skylab can provide a basis for initial estimates of construction related tasks including estimates of learning. Task 2 will analyze the various tasks associated with construction of large mission hardware items (as defined in the SSSAS) and, using the results of Task 1, will estimate times to perform a variety of construction tasks. The intent is to establish a standard for future estimates. Task 3 will validate the time estimates through test considering such possibilities as neutral buoyancy tests, zero-g aircraft trajectories, and one-g tests that are then related to zero-g performance based on Skylab experience, etc. Task 4 will evaluate the tasks under consideration and determine requirements for aids which will enhance performance (e.g., use of a cherry picker platform).

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	6	6	12
(2) Specialized Facilities[1]			
• neutral buoyancy	X	X	
• zero-g aircraft	X		
(3) Funding			
• direct labor	$480K	$480K	$960K
• equipment and material	--	--	--
• facilities	--	--	--
• other	270K[2]	--	270K
	$750K	$480K	$1,230K

F. Target Schedule:



[1] Existing facilities and equipment to be used.

[2] Zero-g aircraft tests.

A. Title: SPACE CONSTRUCTION OPERATIONS SUPPORT REQUIREMENTS

B. Status: The SSSAS and other recent studies addressed the construction of large elements in space to the extent that the mechanical construction techniques were evaluated and hardware requirements for space construction were identified at the sub-system level.

C. Justification: Previous space construction studies were generally limited to the requirements imposed by the direct construction function such as a manipulator system to position personnel and material, and EVA to support the crew's construction functions. The production control interface functions that are common to any construction operation will impose additional requirements and these must be carefully assessed to get the total set of requirements for the space construction system. Of particular significance are the information and the test command and control systems.

D. Technical Plan:

(1) Objective

The objective of this study is to develop techniques for planning, controlling and scheduling on-orbit construction, and determine the additional requirements that are imposed on the space construction system to perform these functions.

(2) Technical Approach

A case study approach will be taken in which 2 or 3 items of mission hardware will be analyzed as the basis for establishing the Construction Operations Support requirements imposed on the space construction system.

Task 1 is to prepare the following data for 2 or 3 selected items of mission hardware: a) detailed manufacturing plan,

b) task procedures, c) part descriptions, d) tool descriptions, and e) checkout procedures.

Task 2 will use the results of task 1 to develop Production Control Concepts including: a) long term production planning, b) daily activity scheduling, c) inspection and status reporting, and d) performance measurement.

Task 3 will establish requirements and procedures for Real Time Construction Operations including: a) receiving and inspection, b) QC inspection and reporting, c) as-built configuration description, d) out-of-position work and work-arounds, e) real time inventory and parts control, f) parts repair, g) tool maintenance and repair.

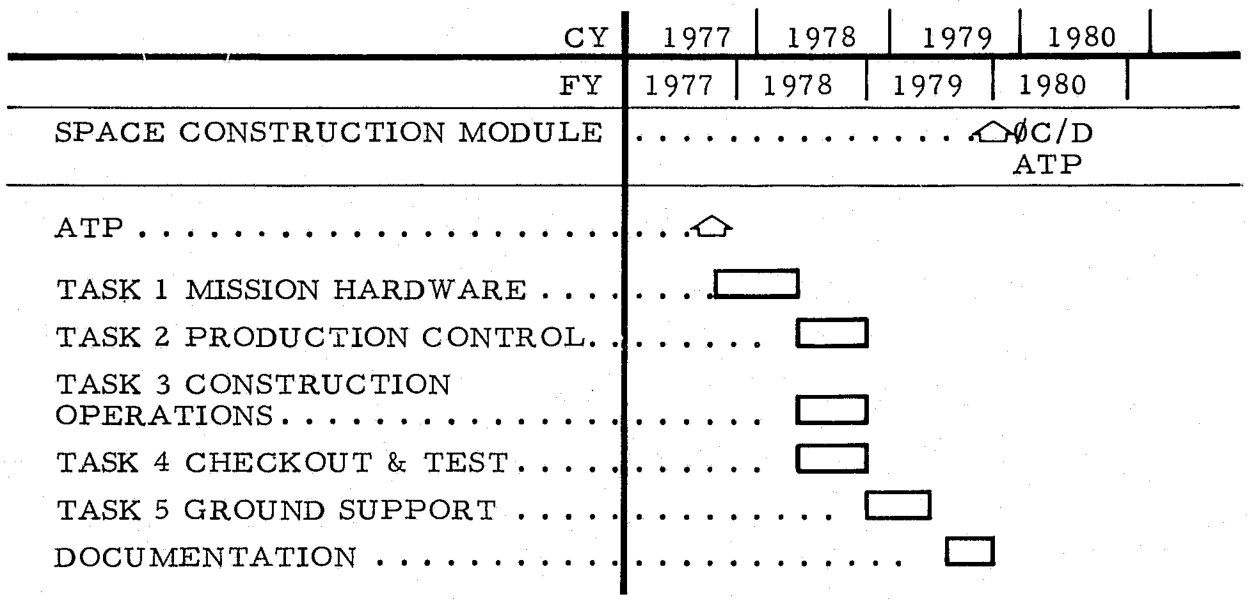
In Task 4 checkout and test procedures and requirements will be determined including: a) test stimuli and response, b) test control (sequencing, parameter limiting, remote command, etc.), c) in-process test (diagnostics) and d) data input, display, recording, reduction, and evaluation.

Task 5 will analyze ground support requirements including training, ground simulators, mockups, real time consultation, and data transmission and storage.

E. Resource Requirements:

	FY 78	FY 79	Total
(1) Man-power (man-yr)	6	4	10
(2) Specialized Facilities		None required	
(3) Funding	$480K	$320K	$800K
• Direct labor			

F. Target Schedule:



A. Title: COMBINED ENVIRONMENTAL EFFECTS ON SPACE STRUCTURES

B. Status: Several examples of environmental influence on space hardware systems have been identified and in some cases even quantitatively understood. These include radiation hazards imposed by energetic charged particles (from both trapped radiation and solar flare particles), electrical charging and arcing caused by plasma flow over the spacecraft, current leakage of high voltage systems through the ionspheric plasma, solar array degradation caused by ultraviolet radiation, meteoroid damage, and several more mundane effects that are well understood, such as thermal problems from solar emissions, forces and torques produced by gravitational and electromagnetic fields, and satellite drag caused by the neutral upper atmosphere. Most of these effects have been studied individually. However, the problem of the combined influence of several of these effects on given systems has not yet been addressed. It may be adequate to design a small system such as a communications satellite to withstand a particular environmental influence (such as spacecraft charging) but for a large system performing several functions it is necessary to consider all of the environmental influences it may encounter.

C. Justification: All proposed space systems will operate in a total environment which will influence many aspects of systems performance. Each system will be constructed to perform several missions. Each mission goal in turn will be affected by this total environment. To date the impact of each specific environmental problem has been addressed individually. However, since the cure for one environmental problem may adversely impact system performance with regard to another environmental influence, the combined environmental effects must be properly considered and input to the system design in order to ensure that the overall mission goals are met.

PRECEDING PAGE BLANK NOT FILMED

D. Technical Plan:

(1) Objective

The overall objective is to examine the interactions of space hardware systems with their total orbital environment including, as applicable, charged particle fluxes (radiation problems for components and personnel), solar electromagnetic radiation including x-ray, visible and ultraviolet (thermal and long-term materials degradation problems), electric and magnetic fields (possible induced currents, forces and torques), ionospheric electrons (charge leakage in low earth orbit), and neutral atmosphere (drag and orbital lifetime problems).

For candidate space systems with several mission goals this SRT item would determine the following:

- Which goals can be met in the chosen orbital environment
- Which missions require materials modifications in order to withstand their particular environmental impact
- Which of these modifications adversely impact other mission goals
- Which sets of missions are then compatible with a given orbit and space environment

(2) Technical Approach

The following tasks will be performed to satisfy this SRT objective:

(a) Identify environmental factors that impact the SCB

(b) Evaluate the SCB design to determine those elements that are significantly impacted by the environmental factors, and identify the affect on mission goals.

(c) Provide a detailed quantitative description of the environment for the elements identified in (2)b.

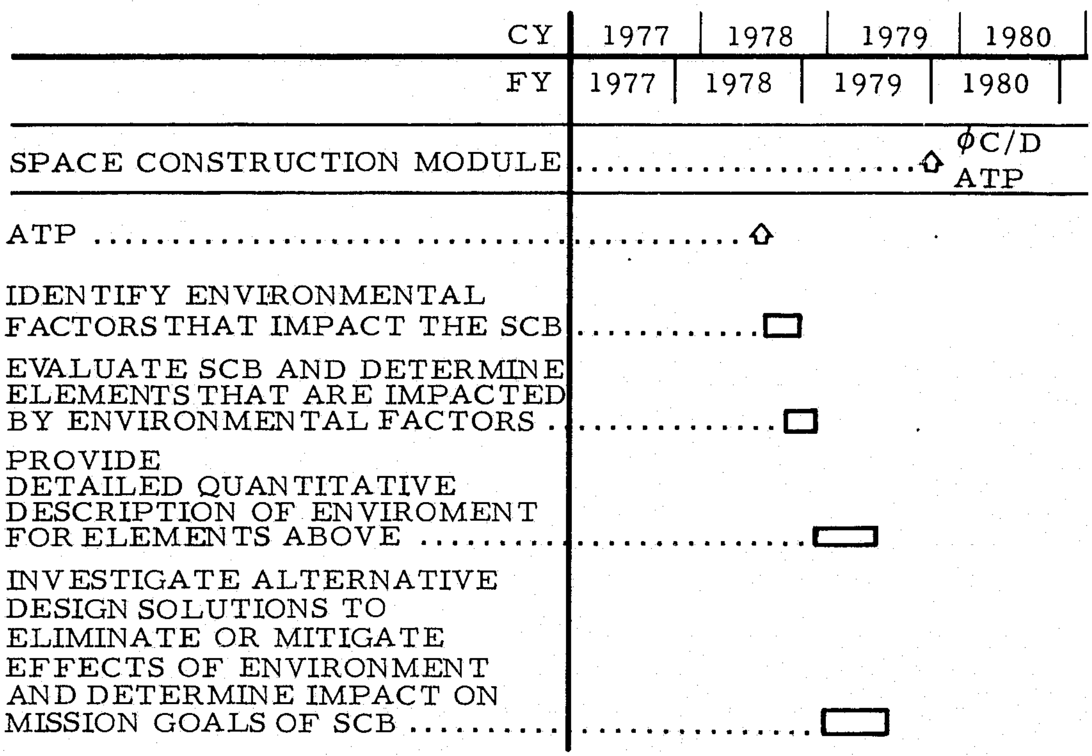
(d) Investigate alternative design solutions to eliminate or mitigate effect of environment and determine impact on mission goals of SCB.

E. Resource Requirements:

		FY 78	FY 79	Totals
(1)	Manpower	1	3	4
(2)	Specialized Facilities		None Required	
(3)	Funding			
	• direct labor	$80K	$240K	$320K

F. Target Schedule:

CR60



A. Title: BERTHING AND DOCKING MECHANISMS

B. Status: These two mechanisms both have the function of attaching elements to a spacecraft or a modular Space Construction Base (SCB), but operate under grossly different dynamic conditions.

A mechanical docking system is the dynamic mechanism for mating a space vehicle (e. g. , orbiter) to a spacecraft or space construction base (SCB). The Orbiter would be the active unit. Operational requirements include: initial contact mechanical guidance, spatial compliance, momentum energy absorption, structural latching, pressure sealing, and subsystem interface connections.

A berthing system is a relatively passive mechanism for mating a module or pallet to a space construction base by means of a reasonably accurate locating system (i. e. , Orbiter Remote Maniuplator or SCB crane). This significantly reduces the time, joining velocity, control, and momentum absorption requirements. Thus, the berthing system has limited initial guidance and reduced spatial compliance requirements, while the requirements for structural latching, pressure sealing, and subsystem interface connections are comparable to a docking system.

Docking mechanisms were used on Apollo and Apollo Soyuz missions. The international docking mechanism of the Apollo Soyuz program may be used on the Orbiter, but in a considerably modified form. Due to the large disparity between berthing and docking loads, this mechanism is not readily adaptable to the low berthing contact loads.

C. Justification: Dynamics analysis of the modular space base buildup has determined that the addition of modules by docking them ' the

SCB directly with the Orbiter is not desirable. Therefore, buildup will be accomplished by means of the Orbiter Remote Manipulator or a SCB crane. Existing docking mechanisms do not fully satisfy the SCB requirements for berthing or docking. This gives rise to the need to investigate new berthing and docking mechanisms or the modification of existing docking mechanisms.

D. Technical Plan:

(1) Objectives

The primary objective is the development of universal berthing and docking mechanism concepts applicable to the Orbiter and the Space Construction Base. Physical and functional berthing and docking requirements will be developed based upon Orbiter-SCB operations to provide the basis for the design of minimum complexity and cost prototype mechanism(s).

(2) Technical Approach

Task 1 is the evaluation of existing docking mechanisms (i. e., the International ASTP and the Orbiter derivative) and the design analysis of their adaptability to berthing.

Task 2 will utilize the refined concepts derived in Task 1 to analytically compare with the berthing and docking requirements for the Orbiter and Space Construction Base. This task will also update the Phase B modular Space Station study results on module interface requirements and establish complete berthing requirements. Computer simulations will be conducted to verify analytical results and further define requirements.

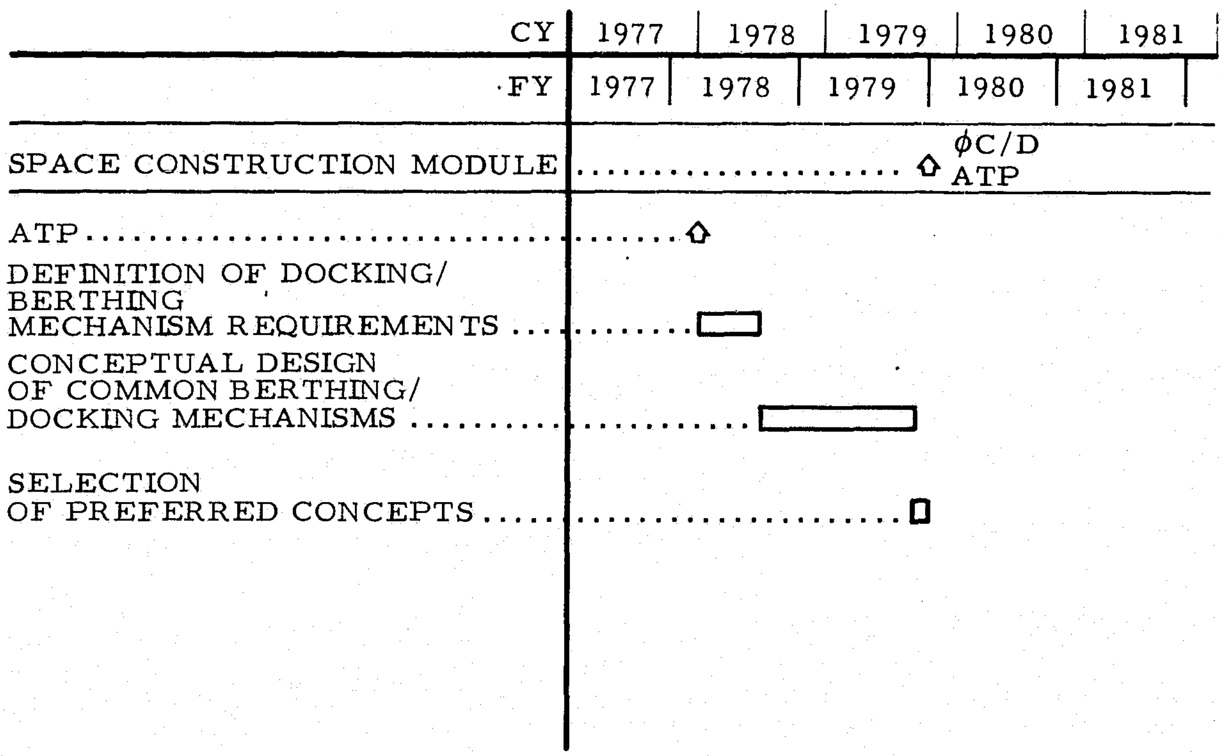
Task 3 will define several new configurations, including a universal androgynous berthing and docking mechanism. These will be consistent with all orbiter Space Construction Base requirements.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	3	3	6
(2) Specialized Facilities		None required	
(3) Funding			
• Direct Labor[1]	$250K	$250K	$500K

F. Target Schedule:

CR60



[1] Includes computer costs

A. Title: FLIGHT CONTROL OF THE SCB

B. Status: Flight control of an SCB has been given a first order definition by JSC during 1976-1977 under Contract NAS9-14958. Several control problems (principal axis tilt, actuation optimization and flexibility) which were encountered require more depth of research and analysis.

C. Justification: Greater depth of analysis in flight control problems for the SCB should be achieved for the present growth sequence and future evolutions in order to establish a firm foundation for the flight viability of the SCB concept.

D. Technical Plan:

(1) Objectives

The objectives of this item are to thoroughly define the flight control of the SCB after having performed research into associated critical technologies and applying them to SCB configurations. The major output will be preliminary flight control specifications.

(2) Technical Approach

(a) Survey and describe SCB configurations, inertial characteristics, and structural dynamics.

(b) Analyze and derive an orientation history for the SCB.

(c) Survey potential actuator (chemical jets, resistojets, electric propulsion, magnetics, aerodynamics, etc.) and sensor (gyros, star trackers, solar trackers, horizon sensors, etc.) applications to SCB.

(d) Synthesize leading candidate flight control mechanizations and simulate in rigid body orbital simulation.

(e) Perform flexible body stability analysis on leading candidates from (d) and optimize control laws for best performance and resource utilization.

(f) Introduce flexible body dynamics into orbital simulation.

(g) Produce preliminary specifications.

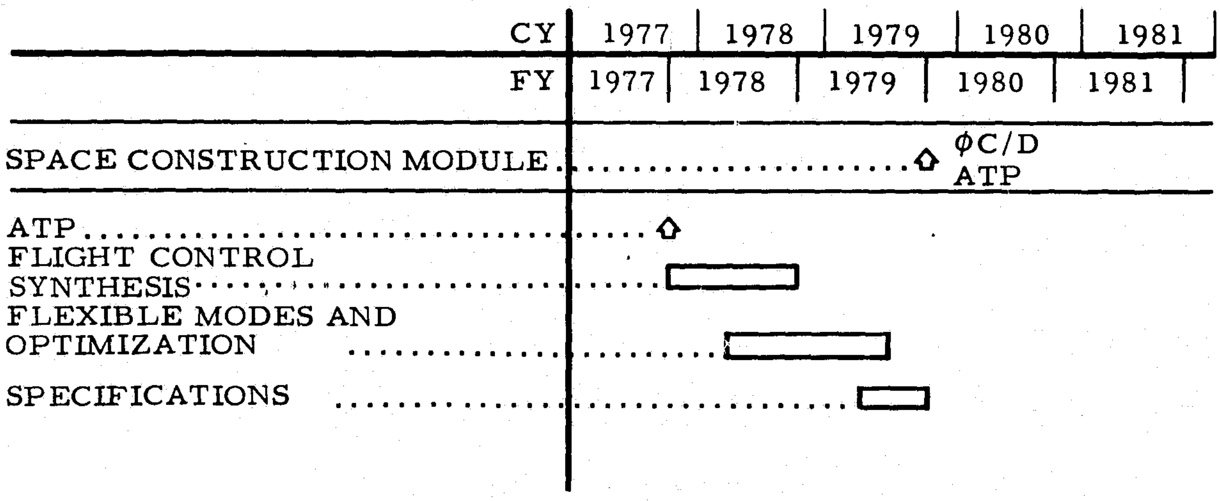
...DING PAGE BLANK NOT FILMED

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	3	4	7
(2) Specialized Facilities		none required	
(3) Funding			
• direct labor[1]	$250K	$350K	$600K

F. Target Schedule:

CR60



[1] Includes computer costs

A. Title: COLLISION AND REPAIR POTENTIAL

B. Status: Current capabilities for estimating the capability of space structures to withstand space collisions are aimed at the micro-meteoroid hazard. The ability to analyze and test the ability to cope with larger and slower particles (e.g., orbiting debris) has not yet been pursued.

C. Justification: Analysis has shown that man-made particles below radar detection size dominate the particle flux hazard in low earth orbit. As more satellites (and attendent particles) are placed in orbit and as manned space systems become larger and extend their useful life, the number of encounters and the damage potential will increase. It is already relatively high for particular orbits. The potential damage mechanisms and repair potential should be assessed.

D. Technical Plan:

(1) Objectives

The objectives are to 1) analyze the potential collision hazard for space vehicles in terms of particle flux, size, and impact velocity, 2) define and determine the potential damage to structural elements, and 3) evaluate ways to repair the damage.

(2) Technical Approach

The approach will be to evaluate the analysis to date and draw out those portions applicable to manned space missions. The potential hazard will then be defined in such terms as probability of encounter, orbit, duration, and size.

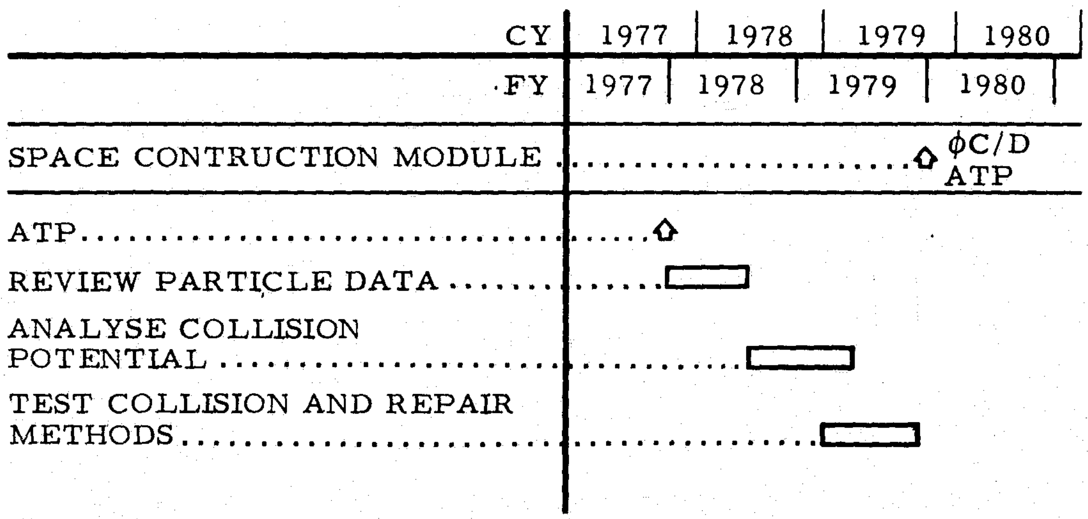
Analysis based on past puncture calculations and test data will be extended to this new regime to theoretically assess the damage potential. Typical structures would then be tested to assess the damage and potential repair capability.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	2	3	5
(2) Specialized Facilities[1]			
• light gas gun or similar facility[2]		X	
• structures lab[3]		X	
(3) Funding			
• direct labor	$160K	$240K	$400K
• equipment and material	--	$ 10K	$10K
	$160K	$250K	$410K

F. Target Schedule:

CR60



[1] Existing facilities to be used.

[2] Needed for test phase.

[3] Needed for damage assessment and repair.

A. Title: ENGINE EXHAUST PLUME INDUCED EFFECTS

B. Status: The exhaust plumes generated by the Space Shuttle on-board attitude control system produce severe impingement pressure, heating, and contaminating particulate environments (unburned liquid droplets, liquid vapor, wall film, and condensed species) potentially damaging to surfaces in proximity to the exhaust plumes. Existing computer codes can be used to calculate the effect of plume impingement on these surfaces.

For most of the region of impingement, the accuracy to which these computer codes calculate the impingement effects is dependent upon the accuracies to which the plume flow field (including nozzle geometry, propellant chemistry, nozzle boundary layer, etc.), and the impingement surfaces are modeled in the codes.

C. Justification: The plume induced environments created during deployment, retrieval, or manipulation of hardware and/or equipment must be defined so these environments can be accounted for.

D. Technical Plan:

(1) Objectives

The primary objective is to define critical plume induced environments (impact pressure, heating, and contamination) and develop operational zones of safety and recommended procedures which can be utilized during simultaneous engine operation and construction to ensure safe and efficient EVA activities and construction.

(2) Technical Approach

Task 1 will be to analyze planned EVA activities including construction techniques and procedures. Various tasks associated with construction and assembly of large hardware (as defined in the SSSUS) will be analyzed as they apply during all types of engine operation (Orbiter, OTV, and any other propulsion device used to manipulate hardware).

Task 2 will utilize these EVA and construction procedure data to analyze the potential plume effects (impact pressures, heating, and contamination) on both the hardware and the astronauts engaged in EVA activities. The potential effects analyzed will be: impact pressures creating unwanted forces and moments on construction hardware being manipulated or assembled; heating of thermally sensitive surfaces, instruments, or the astronauts engaged in EVA activities; and deposition of contaminating particulates on sensitive surfaces such as optical equipment and instruments.

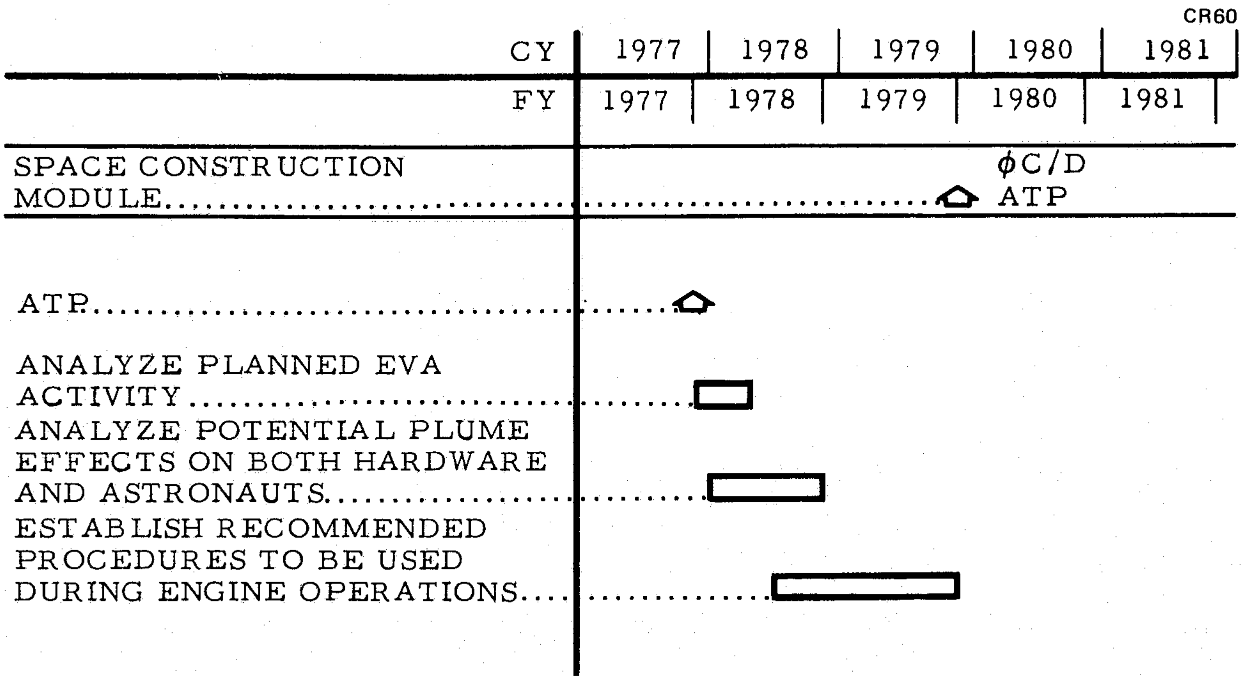
Task 3 will utilize the results of Tasks 1 and 2 to establish recommended procedures to be used during engine operation to ensure efficient hardware manipulation and assembly and ensure the safety of the astronauts. Operational zones of safety, both for the astronauts and hardware, will be established. The zones of safety will depend on the size, shape, and sensitivity of the hardware and for the case of the astronauts, the protective ability of the space suits.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	2	2	4
(2) Specialized Facilities		None Required	
(3) Funding			
• direct labor[1]	$168K	$168K	$336K

[1] Includes computer costs

F. Target Schedule:



A. Title: SPACE RADIATION

B. Status: The impact of radiation hazards on space station design and operations promises to be far greater than for any earlier space missions. Existing capabilities in the radiation analysis field need refinement and further development in preparation for both design and active dosimetry activities. Areas needing particular attention are the extension of the computerized anatomical man (CAM) model into a practical tool for space radiation analysis, more detailed EVA calculation techniques, and the refinement of projection techniques to provide early dose estimation after observation of a solar cosmic ray (SCR) event.

C. Justification: Space programs of the near future will utilize man in a major role including significant amounts of EVA. Current studies show that planned EVA suits provide marginal protection for some missions. More detailed analysis of the environment, dose, and shield design is needed as well as development of the man model. In addition, the current man model should be extended to allow the analysis of the effects of microwave radiation since large microwave radiating devices are potential space program objectives.

D. Technical Plan:

(1) Objectives

The improvement of space radiation analysis capabilities includes a variety of objectives, many of which involve further development of the CAM model. Previously identified minor improvements in efficiency of operation need to be completed. A variable posture capability would allow a study of the effects of normal crew posture changes on organ doses. Additions of physique scaling and a female model are needed to allow dosimetric calculations for individual astronauts. A detailed model of the EVA suit needs to be created to make possible evaluation of the effects of actual localized shielding. Such suit models need to be used in the design of future EVA suits. Similarly, space station geometric models must be created and used during the station planning and design to identify the optimum placement of equipment and stores and to design and locate the biowell and any other special shielding.

The CAM model would be extended to include the potential for dose evaluation of non-ionizing (microwave) radiation. The CAM-related objectives lead to the development of a significantly improved dosimetry system. Data from on-board measurements can then be used to provide a realistic assessment of dose received by each crew member in real time. This dosimetry system must include a solar cosmic ray dose projection capability.

(2) Technical Approach

The approach will be to extend the current CAM model to incorporate potential space suit designs, to model potential space station modules for detailed analysis, and to extend and automate the EVA dose analysis techniques developed during the Space Station study. The CAM model will be tested for veracity using a known source in a Radiation Test Lab. The CAM model will be used as a calculational base to form the needed non-ionizing validation model.

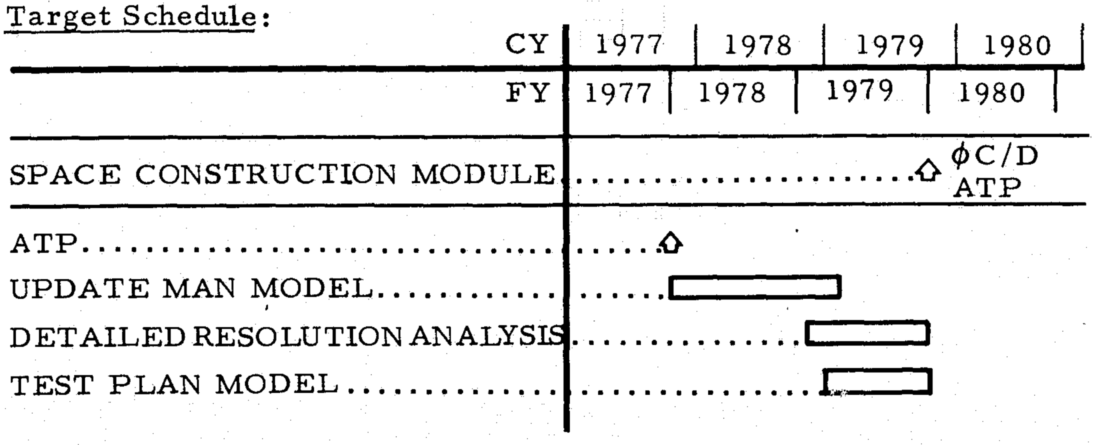
In the area of SCR dose projection, several schemes have been proposed to provide an early warning of a solar event. These schemes would be evaluated, leading to the selection and development of the best early warning system. This capability will have an impact on mission operations, enabling the crew to occupy the biowell before the onset of high dose levels from large solar events. Protection of the crew from the radiation arriving during the early phase of large events and from the full exposure to lesser events must also be considered in EVA suit design.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	2	2	4
(2) Specialized Facilities[1]			
• radiation test lab		X	
(3) Funding			
• direct labor	$160K	$160K	$320K

CR60

F. Target Schedule:



[1] Existing facility would be used to test the accuracy of the models developed.

3.2 SPACE SYSTEMS TECHNOLOGY PROGRAMS

This category of activities requires the initiation of scientific and engineering analysis and/or testing of capabilities, methods and techniques. These activities should be completed prior to the indicated applicable SCB element milestone if program risk is to be minimized. The hardware activities associated with these SRT efforts should not extend beyond those required to demonstrate validity.

The SRT items identified for this category are as follows:

- Space Crane Technologies
- On-orbit Fastening and Joining
- On-orbit Structural Alignment
- On-orbit Structural Repair
- Solar Arrays
- Electrical Power System Energy Storage
- OTV (Orbit Transfer Vehicle) Technology

A. Title: SPACE CRANE TECHNOLOGIES

B. Status: The definition of the Space Crane for the SCB has progressed to the status of a preliminary specification based on first order operational and design requirements. This specification is compatible with the SCB concept developed in 1976-1977 by JSC under Contract NAS9-14958. Development of a similar device (the Shuttle RMS) is in the advanced stages; however, the requirements for important elements of the Space Crane are not now sufficient for SCB needs. These elements include end effectors for construction and repair, interactions between controls and the dynamics of extremely long crane arms, and software architecture.

C. Justification: Three general areas of work are required:

(1) A study is needed of Space Crane end effectors to support construction, repair and payload movement. This work would provide the proper analysis to assure that the requirements for the Space Crane are well founded.

(2) A study is needed to successfully solve the controls-dynamics interface. This effort will evolve the requirements for control of a long thin crane arm with sufficient response over the entire range of attitudes and payload characteristics.

(3) A study is needed to establish the requirements for the total software architecture for the Space Crane and to solve particular software problems associated with multi-degrees of freedom, combined maneuvers, and obstruction avoidance.

D. Technical Plan:

(1) End Effectors

Objectives

The principal objectives of this effort are to develop definitive requirements for end effectors that can support the various operational needs of the SCB program. These devices will then be tested in a ground-based Space Crane simulation facility to evolve requirements.

Technical Approach

(a) Perform survey, systems analysis, and categorization of requirements for end effectors to meet operational needs.

(b) Analyze each end effector to derive an optimum design solution to each requirement.

(2) Controls Dynamics

Objectives

The principal objectives of this study are to provide an optimized controls-structure design solution for the Space Crane articulated arm. A demonstrated mathematical simulation of the dynamics and control of the arm and the associated controls and structural specifications will be the essential outputs of this effort.

Technical Approach

(a) Perform parametric analysis of structural dynamics characteristics as a function of arm stiffness and payload mass and overhang.

(b) Synthesize control system characteristics, including joint servos and damping feedback to best accommodate the dynamic modes.

(c) Analyze multi-servo coupling dynamics and analyze cross-axis coupling at critical attitudes.

(d) Develop full flexible dynamics and servo mathematical simulation of the Space Crane arm.

(e) Optimize response and control margins, and summarize design requirements.

(3) Software Architecture

Objectives

The principal objectives of this study are to develop the software architecture requirements for the Space Crane, and to derive software for special operational functions and constraints.

Technical Approach

(a) Survey and analyze all functional requirements for the Space Crane and establish a functional hierarchy for the software.

(b) Define interfaces between functional blocks.

(c) Define specific tasks requiring special definition and software generation, e.g.,

- Obstacle avoidance
- Multi-degree of freedom angle commands
- Combined axis maneuvers

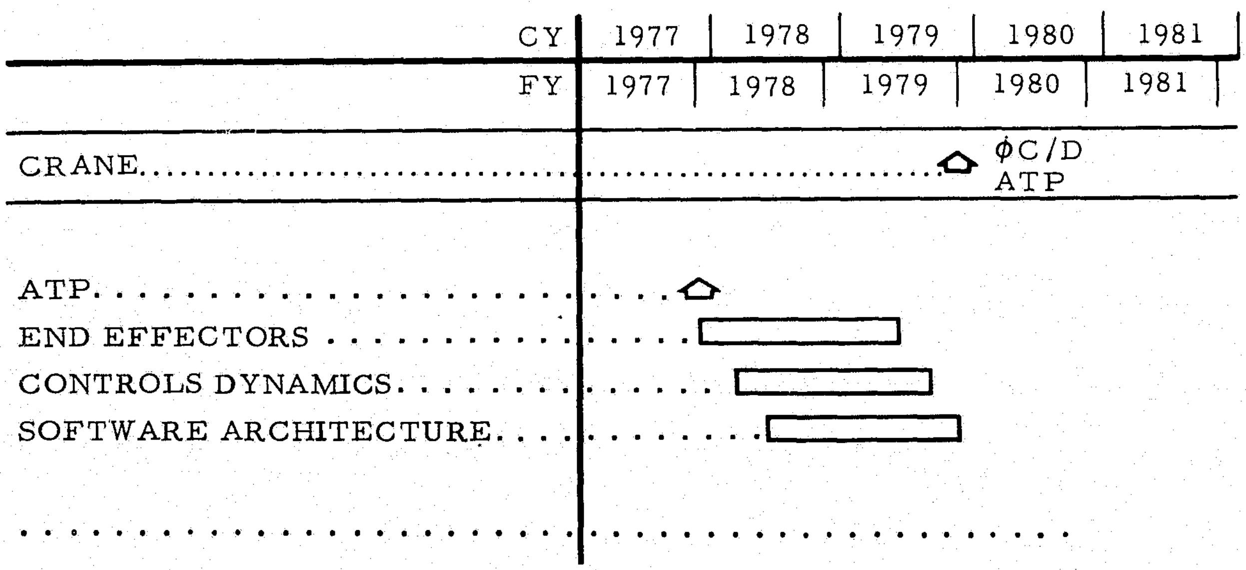
(d) Develop software requirements for specific identified function tasks.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)			
End Effectors	3	6	9
Controls Dynamics	6	10	16
Software Architecture	6	6	12
	15	22	37
(2) Specialized Facilities	none required		
(3) Funding			
• direct labor[1]	$1220K	$1800K	$3020K

F. Target Schedule:

CR60



1-Includes computer costs

A. Title: ON-ORBIT FASTENING AND JOINING

B. Status: Limited joining tests of mechanically-fastened columns and beam members are being conducted by NASA/MSFC in its neutral buoyancy facility, and other preliminary tests have been conducted as a part of a contract to evaluate remote manipulators and assembly techniques for large space structures. However, the tests conducted to date have been limited in scope in terms of structural materials evaluated and types of joints.

C. Justification: While the fastening and joining tests simulating assembly of structures in space conducted to date have been meaningful, a more comprehensive program is required that will include the full range of promising materials and structural concepts. SRT for evaluation of candidate fastening and joining techniques is required as a basic part of the large space structures technology development program because of the significant impact joining techniques will have on final selection of structural designs and materials used for manufacturing large space structures. As an example, composite structures can require different joining techniques and processes than those used with metal structural assemblies, and such differences can have a significant impact on costs of space manufacturing and space assembly operations. The extent of required EVA operations can also be impacted significantly by fastening and joining techniques selected for space assembly of large structures. The attachment of non-structural elements such as antenna elements, reflective surfaces, photovoltaic cells, and power distribution lines will also require adequate technology development to ensure the selection of viable concepts for large space systems. Because fastening and joining techniques can affect the initial costs, maintenance costs, EVA requirements, and operational performance of large space structures, a technology program to assess such effects is required.

D. Technical Plan:

(1) Objectives

The primary objectives of this SRT item are to evaluate cost, weight, space manufacturing and support equipment requirements, and EVA requirements that are associated with various candidate fastening and joining approaches for large space structures. Both metallic and non-metallic structural concepts will be evaluated. Fastening and joining processes will include mechanical fasteners, adhesives, welding, diffusion bonding, and integral bonding or cocuring.

(2) Technical Approach

(a) Establish design requirements to be used as a basis for defining fastening and joining concepts to be evaluated.

(b) Develop candidate design concepts for structural elements and attachment of non-structural elements.

(c) Select candidate test concepts representing typical segments of large space structures. Conduct preliminary tests to evaluate joining and fastening approaches using typical elements of both metallic and non-metallic structures.

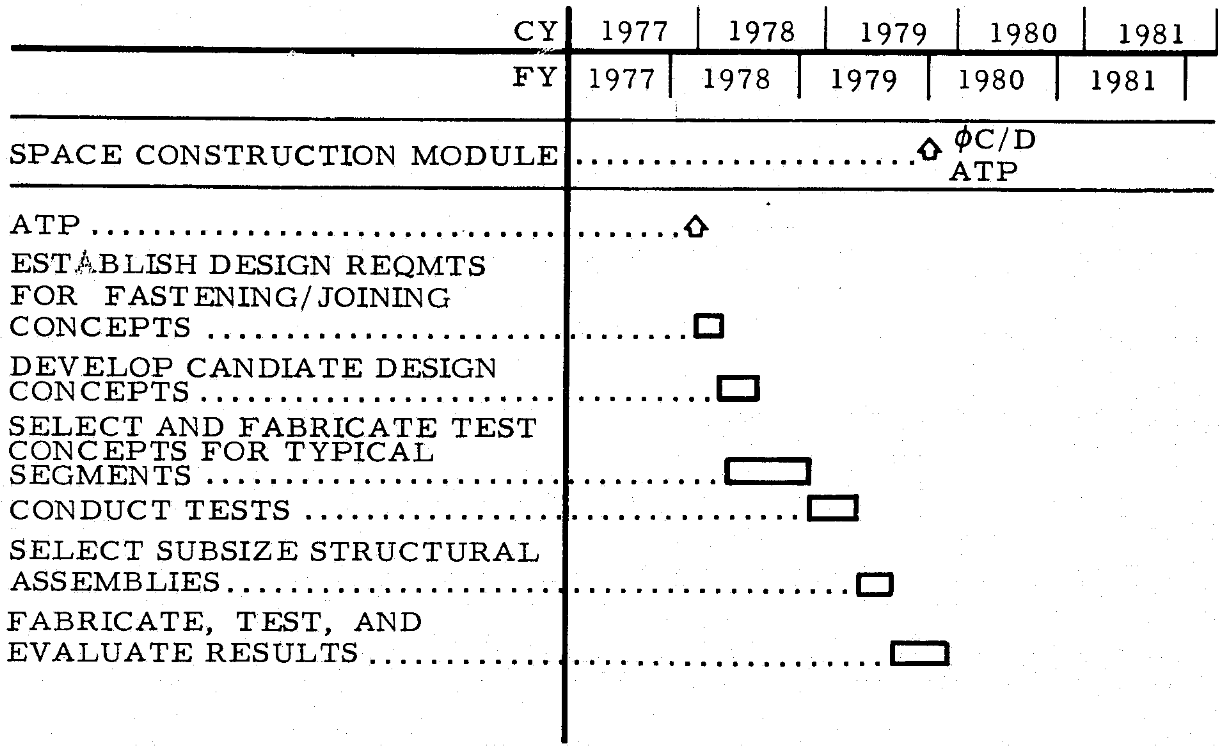
E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	1.5	6.5	8
(2) Specialized Facilities[1]			
• neutral buoyancy	--	X	
(3) Funding			
• direct labor	\$120K	\$520K	\$640K
• equipment and material	30K	90K	120K
	\$150K	\$610K	\$760K

[1] Government Furnished Facility – NASA Neutral Buoyancy Tank

F. Target Schedule:

CR60



A. Title: ON-ORBIT STRUCTURAL ALIGNMENT

B. Status: Structural alignment problems related to the assembly of large space structures have been studied to a limited extent in programs to evaluate use of remotely controlled manipulators for assembly of large space structures. However, those studies have been conducted with only a limited size of structural assembly and with limited techniques of measuring structural alignment.

C. Justification: While the experiments conducted to date have provided initial evaluations of alignment requirements, further experimentation is required with larger structural assemblies using a number of candidate alignment techniques. Furthermore, EVA requirements, use of mobile maneuvering units (MMU), and use of teleoperators should be studied and evaluated to determine the most promising approaches to achieving required structural alignments. The structural alignment achievable with various joining techniques and space manufacturing methods also needs to be determined, as well as the effects of structural material selection on alignment attainable in orbital assembly of large structures.

D. Technical Plan:

(1) Objectives

The principal objectives are to define the required structural alignment of large space structures used by various space systems, and to analytically and experimentally evaluate the effectiveness of alignment techniques, structural joining methods, and structural materials in achieving the required alignment precision. EVA requirements and the use of MMU and teleoperators will also be evaluated.

(2) Technical Approach

(a) Define structural alignment requirements for large antenna systems, solar power arrays, and microwave power transmission systems

(b) Evaluate candidate alignment techniques and fabrication and joining processes to determine their effects on attainable structural alignment of large space structures.

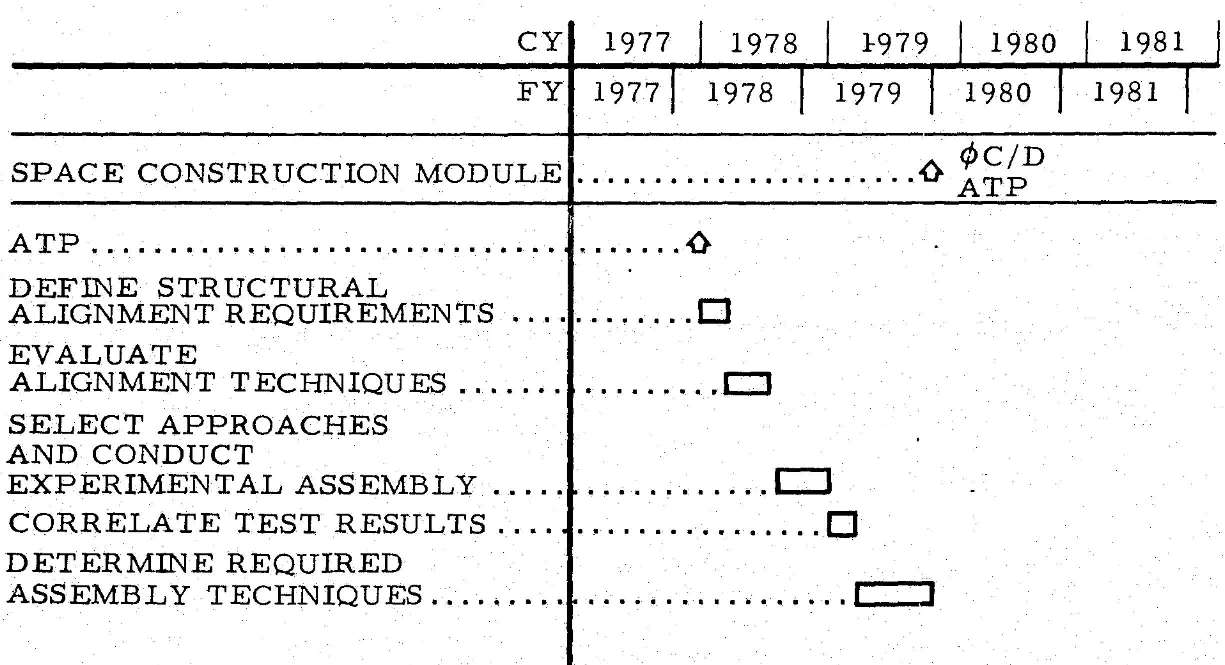
(c) Select most promising approaches and conduct experimental assembly of representative structural members. Correlate test results with analysis. Determine required assembly techniques as a function of system alignment requirements. Assess crane and EVA requirements, and use of MMU or teleoperators.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	3	8	11
(2) Specialized Facilities		none required	
(3) Funding			
• direct labor	$240K	$640K	$880K
• equipment and material	20K	80K	100K
	$260K	$720K	$980K

F. Target Schedule:

CR60



A. Title: ON-ORBIT STRUCTURAL REPAIR

B. Status: Very little pertinent data is available in the literature on the subject of orbital repair of large composite space structures. Repair techniques are presently being developed for both commercial and military aircraft composite structures.

C. Justification: Techniques for the repair of composite structures on-orbit will differ significantly from techniques being developed for ground repair of aircraft composite structures because of the effects of the orbital environment (i.e., vacuum, weightlessness, and cyclic thermal conditions) and the unique operational requirements of large space structures. For example, composite structure repair on-orbit should avoid wet-buildup ply patches because (1) resins will foam or boil in vacuum, and (2) zero-g conditions coupled with reduced operator efficiency will make repairs using built-up patches extremely difficult to accomplish. On-orbit repair techniques for composite structures will also differ from those for aircraft structures because they will have to take into account the unique requirements imposed by stiffness, strength, environmental, maintainability and serviceability considerations for large space structures, e.g., 30 year service lifetime in a cyclic thermal environment.

D. Technical Plan

(1) Objectives

The objective of this program is to develop orbital repair techniques for large composite space structures.

(2) Technical Approach

(a) Identify and analytically evaluate repair procedures for candidate composite structures and materials. Evaluation and screening of repair techniques will take into account large space structure operational requirements and will consider repair costs.

(b) Develop a test program for evaluation of selected repair techniques for various composite materials. The test plan will include mechanical and thermal property testing to evaluate repair procedures. Space environment simulation testing will be used to verify details of selected repair procedures.

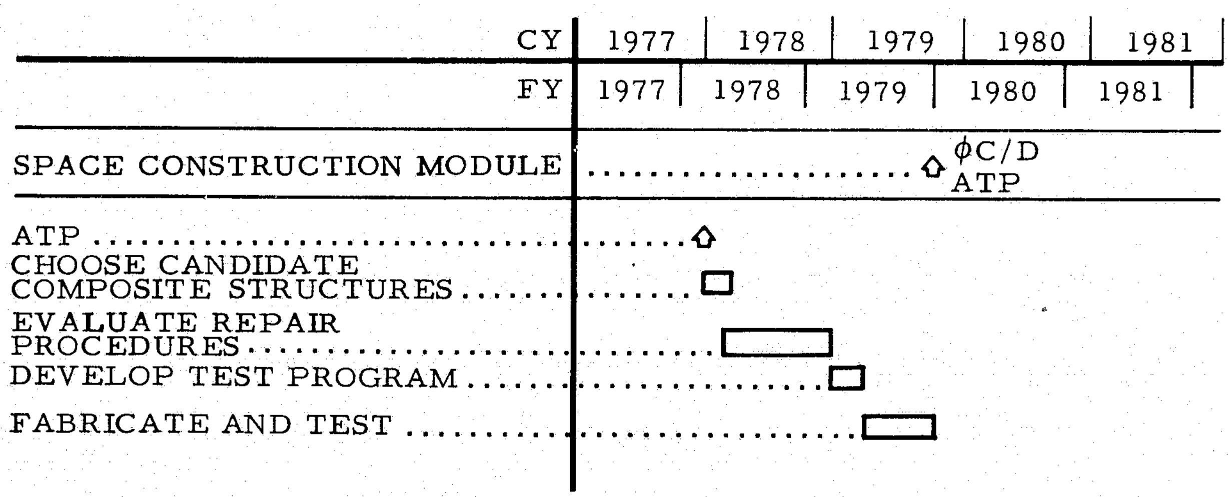
(c) Fabricate and test repaired structure specimens of candidate composite materials.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	2	3	5
(2) Specialized Facilities			
• neutral buoyancy[1]		X	
(3) Funding			
• direct labor	$160K	$240K	$400K
• equipment and materials	5K	20K	25K
	$165K	$260K	$425K

F. Target Schedule:

CR60



[1] NASA Government Furnished Facility

A. Title: SOLAR ARRAYS

B. Status: The Solar Electric Propulsion (SEP) solar array technology currently being developed by NASA is planned to be employed for the initial SCB power system — the Power Module. The Power Module is assumed to be accomplished with other than SRT funding. The second generation power system for the SCB (the Power Platform) will require large continuous roll solar cell blankets. System analyses of the Power Platform are required to define specific requirements and critical issues.

C. Justification: Definition of the Power Platform solar array system is required in order to establish solar cell blanket requirements. Subsequently, development of continuous roll blankets and related attachments is required. These items are necessary to permit mission planners to confidently design a cost- and mission-effective Power Platform. In addition, further improvement of solar cell and solar cell blanket performance and cost is needed to reduce the size, weight and cost of the large and expensive solar cell blankets.

D. Technical Plan:

(1) Objectives — The objectives of the SRT efforts for the SCB-related solar array activities are:

(a) Definition of the Power Platform design requirements, the program plan and the critical technology issues.

(b) Extrapolation of the SEP solar cell blanket technology to large continuous blanket rolls along with development of attachment concepts suitable for their deployment onto space fabricated structures.

(c) Improve efficiency, weight and cost of solar cells.

(d) Verify long-term operation of solar cell blanket in the space environment.

(2) Approach — The approach for the various SRT objectives is as follows:

(a) Conduct a Power Platform program definition and preliminary design study to define the unique solar array blanket and blanket attachment requirements. The study will start with an analysis of Power Platform requirements and conclude with a preliminary design and program plan. It will be completed in FY 1978 to permit blanket development prior to the start of Phase C/D in mid-1981.

(b) Design, fabricate, roll and unroll, attach, and evaluate small section of continuous blanket roll.

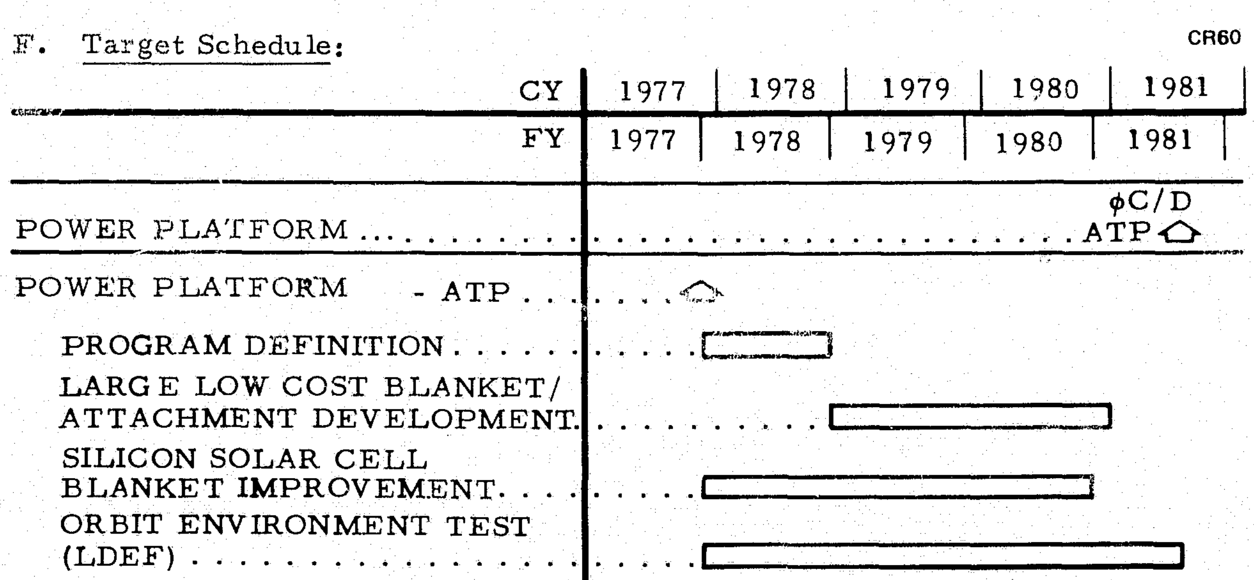
(c) Studies, research and development will be conducted on solar cell and solar cell blanket efficiency improvement and cost reduction, drawing on the ERDA program to the maximum possible extent.

(d) Space environment tests will be conducted on the SEP solar cell blanket and on attractive alternative designs and materials for the Power Platform. These tests should be accomplished on the Long Duration Exposure Facility (LDEF).

E. SRT Resources Requirements:

	FY 78	FY 79	FY 80	FY 81	Totals
1. Manpower (man-yr)	4	4	3	1	12
2. Specialized Facilities	-	-	LDEF	-	-
3. Funding					
a. Direct Labor	$ 320K	$320K	$240K	$ 80K	$ 960K
b. Equipment & Material	50K	150K	50K	80K	250K
	$ 370K	$470K	$290K	$ 80K	$1210K

F. Target Schedule:



A. Title: ELECTRICAL POWER SYSTEM ENERGY STORAGE

B. Status: Lightweight, long life and reliable energy storage for the eclipse portion of the Space Construction Base (SCB) orbit is a traditional energy storage problem. Much work has been accomplished on Ni-Cd batteries by NASA and the USAF, and they have performed reasonably well, although they are heavy and offer marginal life and reliability for the SCB mission.

Significantly less study has been devoted to alternative storage devices. NASA has ongoing regenerative fuel cell system work, which should be oriented toward long life and expanded. The USAF and Comsat have Ni-H_2 battery programs aimed at GEO application. NASA is doing some Ni-H_2 battery testing. This work needs to be expanded and oriented toward: (1) LEO manned applications and (2) proof of suitable zero g operation by flight test. The discussion herein is based on the Power Platform application. The Power Module is assumed to be accomplished with other than SRT funding.

C. Justification: Because of schedule constraints, the initial SCB power source — the Power Module – will employ existing technology Ni-Cd batteries. The second generation SCB power source requires a longer life and more reliable energy storage device. This will appreciably reduce the SCB Power Platform costs by minimizing crew maintenance and replacement operations and by reducing Shuttle logistics costs. Lower weight will also reduce Shuttle logistic costs.

D. Technical Plan:

(1) Objectives

The objectives of this SRT effort for the Power Platform are:

(a) Program Definition — Definition of the Power Platform system design, the program plan and the critical energy storage system issues. This item was also included (with costs) under the "Solar Arrays" SRT item.

(b) Ni-Cd Batteries — Demonstration of a minimum 2-year operating life for advanced Ni-Cd batteries prior to the August 1981 Phase C/D start for the Power Platform.

(c) Regenerative Fuel Cell System Design and Vehicle Integration — Definition of the system requirements, characteristics and vehicle integration (e.g., maintenance and replacement schemes).

(d) Fuel Cell Development — Evaluation and demonstration of the life characteristics of fuel cells on a small scale basis, along with a system design and development plan.

(e) Water Electrolysis Development — Preparation of a water electrolysis cell system design and program plan in conjunction with additional life demonstration.

(f) $Ni-H_2$ Battery — The $Ni-H_2$ battery design definition, battery development and life demonstrations for LEO conditions, and a demonstration of LEO zero g suitability.

(2) Technical Approach

The approaches for the various SRT objectives are as follows:

(a) Program Definition — A Power Platform program definition and preliminary design study will be initiated to define the unique energy storage system requirements and design approaches. The study will start with an analysis of Power Platform requirements and conclude with a preliminary design and program plan. It will be completed in late CY1978 in order to permit the development of responsive energy storage system technology prior to the start of Phase C/D in mid-1981.

(b) Ni-Cd Batteries — An advanced Ni-Cd battery design, that is responsive to the requirements of the manned SCB Power Platform program, will be designed and developed based on conservative technology that can be demonstrated by the August 1981 Phase C/D start. The battery will be based on 100 A-H size cells. The resulting battery concept will be incorporated into the battery life test program in sufficient time to permit two years of real time life testing prior to the Phase C/D start. Accelerated life testing will also be employed.

(c) Regenerative Fuel Cell System — The fuel cell system design and vehicle integration analysis/study will be completed in parallel with the Power Platform program definition study and as early as practical to establish requirements for the major component (e.g., fuel and water electrolysis cells) design and development programs.

(d) Fuel Cell Development — The fuel cell system design will be responsive to it in parallel with the overall regenerative fuel cell energy storage system design and integration study. A preliminary design will be accomplished on the fuel cell system sufficient to identify life-limiting technologies and/or configurations. Also, small scale samples of the fuel cell stock will be put on test as soon as practical using the expected SCB operating conditions for real time tests. Accelerated life tests will also be run.

(e) Water Electrolysis Development — The water electrolysis system design will be responsive to and in parallel with the overall regenerative fuel cell energy storage system design and integration study. The life limiting elements of the design will be put on test two years prior to Phase C/D. Also, small scale samples of the electrolysis cell stack will be put on test as soon as practical, using the expected SCB operating conditions for real time tests. Accelerated life tests will also be run.

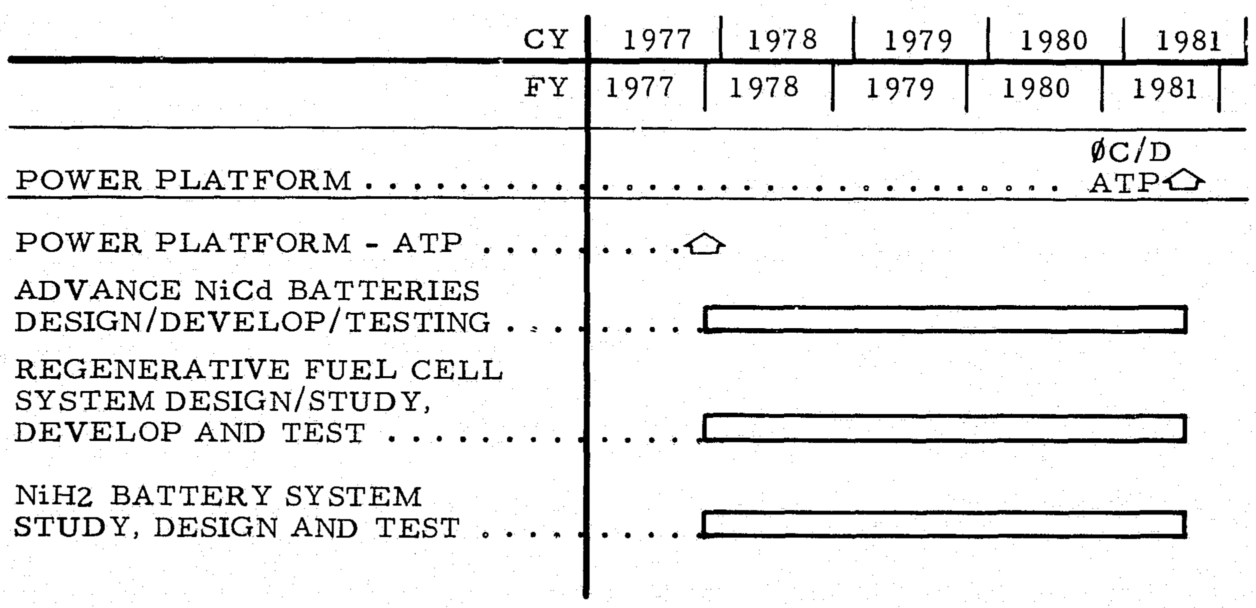
(f) Ni-H_2 Batteries — A battery system study and design is required for the application of Ni-H_2 batteries to a manned spacecraft/ e.g., maintenance, replacement and cooling studies are required. Charge control system studies are also needed. This should occur soon, in order to focus the development program. Very little work has been done for LEO applications; a key Ni-H_2 battery need is to determine usable energy densities and life under LEO orbit conditions. This will be started as soon as practical, measuring performance and life for a range of DOD's from 10-60% and temperatures from 0-50 °C. In addition an orbital flight test program is needed to assure electrolyte location stability for prolonged duration in zero-g in LEO. This should be accomplished with a few cells as a Shuttle experiment.

E. SRT Resources Requirements:

	FY 78	FY 79	FY 80	FY 81	Totals
(1) Manpower (man-yr)	7	7	3	3	20
(2) Specialized Facilities		None Required			
(3) Funding					
• Direct Labor	$560K	$560K	$240K	$240K	$1600K
• Equipment & Materials	80K	225K	--	--	305K
	$640K	$785K	$240K	$240K	$1905K

F. Target Schedule:

CR60



MCDONNELL DOUGLAS

A. Title: OTV (ORBIT TRANSFER VEHICLE) TECHNOLOGY

B. Status: Existing technology and design capability can provide geosynchronous transfer capability on a large scale. However, the high mass factions required suggest that monies spent to improve efficiency and performance would be cost effective.

C. Justification: Manned space programs will involve Shuttle-like traffic between low-earth orbit and geosynchronous orbit. The cost effective accomplishment of this task will require the utilization of high performance OTVs. Technology work is needed to assure their readiness when needed.

D. Technical Plan:

(1) Objective

The objective is to establish design characteristics for a high performance OTV that are feasible in the 1990 era.

(2) Technical Approach

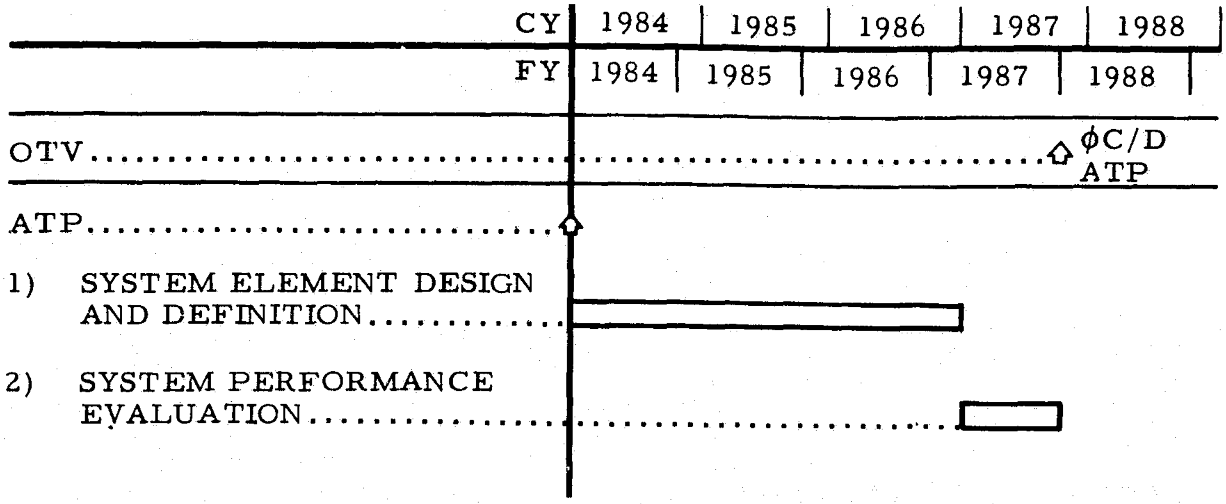
The approach will be to review supplier data and technology plans to assess the projected component capabilities. These would then be assembled into an OTV system design for evaluation. Performance, cost, and sensitivity studies would then be accomplished to establish a potential design.

E. Resources Requirements:

	FY 84	FY 85	FY 86	FY 87	Totals
(1) Manpower (man-yr)	1	2	1	1	5
(2) Specialized Facilities			none required		
(3) Funding					
• direct labor	$80K	$160K	$80K	$80K	$400K

F. Target Schedule:

CR60



3.3 APPLICATIONS

These SRT items are primarily addressed to extended and more detailed study of mission-oriented phenomena and objective element design approaches. The hardware-related items also include demonstration of feasibility for crucial elements of the designs.

The SRT items included in this category are as follows:

- SPS Research and Development Test Planning
- Thermal Gradients and Distortion Effects in Large Structures
- Dynamics and Control of Large SPS Space Structures
- Radiometer Design Development
- Multi-beam Lens Antenna
- Space Processing Environmental Impacts

A. <u>Title</u>: SPS RESEARCH AND DEVELOPMENT TEST PLANNING

B. <u>Status</u>: Actual experience in constructing large structures in space is totally lacking. In fact, the vast size of the operational solar power satellite (SPS), in excess of 140 sq km, places its construction in a class beyond any human experience. Since construction costs are a critical factor, a reliable estimate of this process is necessary for any decision to proceed with the project. But an accurate analysis of aerospace construction and assembly costs is difficult, even with an extensive experience background. In the case of orbital construction, adequate experience may not be gained on the ground. This is particularly true of any estimate involving human productivity in space.

Equally crucial to realization of a practical and economic space solar power system is the ability to form very tightly controlled beams of microwave energy. This control must be exercised to a degree not previously attempted. While this is clearly feasible, practical development of such order-of-magnitude improvements will involve extensive development testing of prototype components. In the case of the SPS, ground development testing of the large-scale microwave phased array antenna to the required accuracy may be impractical within current technology.

C. <u>Justification</u>: A difficult problem then faces NASA in planning SPS research and development: Which test objectives must be accomplished in space and what tests can be more economically done on the ground while retaining technically valid results? A detailed study of this question undertaken now can be based upon the results of on-going NASA contract studies on SPS systems. This would not only result in rational guidelines for ground-based SRT directed at SPS but also support plans for manned space flight activities by documenting either possible alternate ways of accomplishing test objectives or the reasons why ground tests are not feasible.

D. Technical Plan:

(1) Objective

The study is to provide a set of research and development test plans leading to the production of a prototype SPS. Plans are to concentrate on tests where either the space environment must be simulated or the test actually undertaken in space. If a ground test is impractical, the reasons are to be detailed; if both modes are feasible, test plans for both are to be derived and compared.

(2) Technical Approach

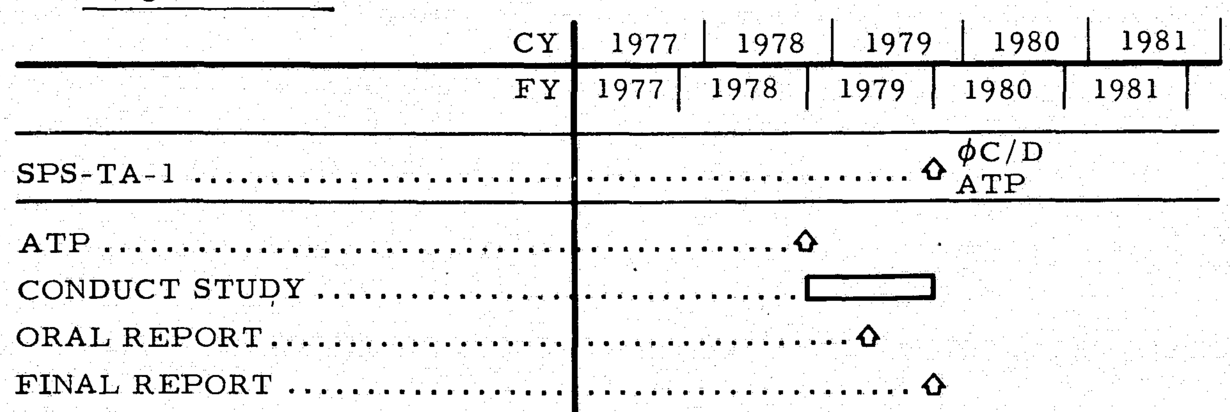
Utilizing the results of on-going systems studies (Boeing and Rockwell), a set of detailed objectives will be derived for the early (prior to a major pilot plant) tests necessary to validate the technical concept and cost estimates. Concentrating on those that require simulation of the space environment, plans (including concepts for all test hardware and instrumentation) will be derived for both space and ground tests to meet the objective. No objective will be assumed impossible for a ground test. A mechanization concept for ground test will be derived for each objective. Alternate modes will be compared on the basis of achievable technical results, technical risk, and costs.

E. Resource Requirements:

	FY 79
(1) Manpower (man-yr)	5
(2) Specialized Facilities	none
(3) Funding	
• Direct Labor	$400K

F. Target Schedule:

CR60



A. Title: THERMAL GRADIENTS AND DISTORTION EFFECTS IN LARGE SPACE STRUCTURES

B. Status: Past and recent studies of large space structures have shown that significant temperature differentials can occur on opposite sides of a large structure while in orbit. These thermal variances over the structure cause structural deformations which may degrade the performance of the structure. The work in this area, thus far, has approached this problem mostly in an extremum or parametric manner and has not provided specific details of either the thermal loading or the resulting distortion effects.

C. Justification: Solar power satellites, including their associated microwave power transmission system (MPTS) antennas, as well as other antenna structures will be subjected to large temperature variations during orbit. These temperature variations may range approximately ±400°F over the surface of the structure. For certain antenna structures the thermal distortion which results does not have to be very large in order to cause significant degradation in antenna performance. Parametric studies of various mechanical and thermal loads on typical large space structures have shown that the aforementioned thermal distortions may have a major influence on the design of the structure.

D. Technical Plan:

(1) Objectives

The principal objectives are to define quantitative temperature variations over a typical MPTS antenna structure and a typical multi-beam lens antenna structure in geosynchronous earth orbit, and to determine the distortions of the structures as a result of those thermal loadings. This SRT item will also study the effects of varying aspects of the structural design of the antenna on alleviating the distortion of the structure.

(2) Technical Approach

(a) Select a typical MPTS antenna structure and a typical multi-beam lens antenna structure from previous system or technology studies. Define tolerable structural deformations over the structure as a function of antenna performance.

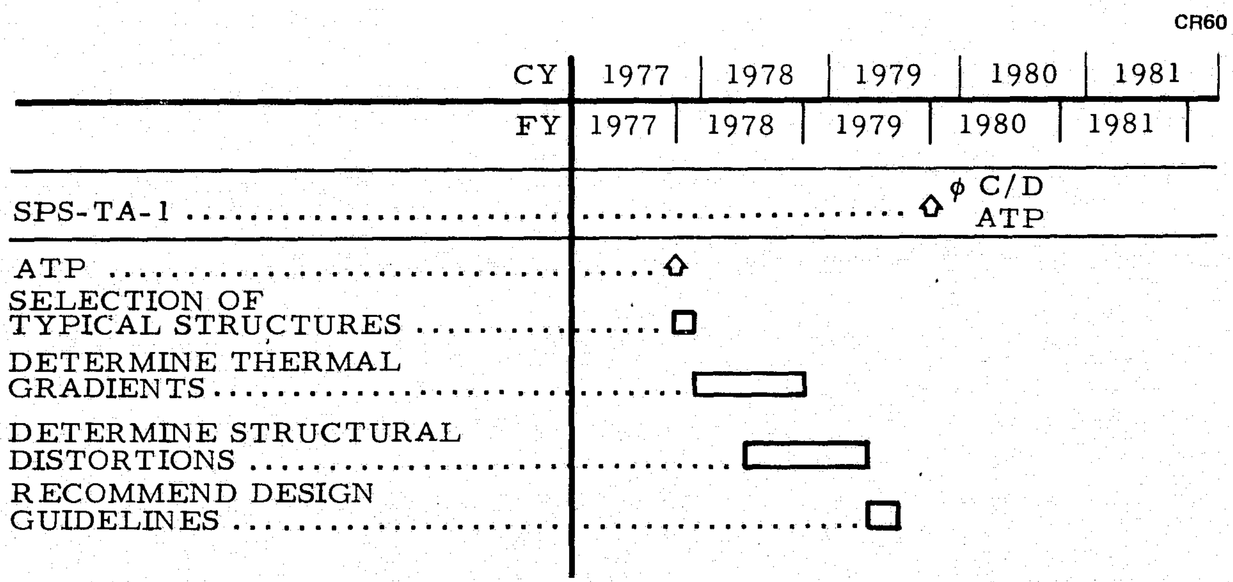
(b) Define orientation requirements of the antenna during orbit. Determine thermal environment, absorption/reflectivity characteristics of the structure, and thermal gradients over the surface of the structure during orbital traverse.

(c) Establish structural distortions as a function of orbital position. Determine the effects of varying basic design parameters of the structure on these distortions. Recommend design guidelines for antenna structures.

E. Resource Requirements:

	FY 78	FY 79	Totals
(1) Manpower (man-yr)	1.5	1.5	3
(2) Specialized Facilities		none required	
(3) Funding			
• direct labor	$120K	$120K	$240K

F. Target Schedule:



A. Title: DYNAMICS AND CONTROL OF LARGE SPS SPACE STRUCTURES

B. Status: During 1976 and 1977, NASA sponsored several contractor and in-house studies associated with design characteristics of a large Solar Power Satellite (SPS). In these studies, some aspects of dynamics and control were addressed, but not in a deep or comprehensive manner. During this time period, studies of Space Construction Base configurations have concentrated on "close-in" construction, and very little has been studied relative to the later SPS construction problems. Several major problem areas should be addressed relative to construction and operation of an SPS. The main ones are (1) control in LEO during construction, (2) control and thrusting during transfer to GEO, and (3) solar collector and antenna pointing during operations at GEO. This presumes that a general design and construction approach for an SPS will exist before this SRT item commences, and that the SPS approach will evolve in parallel with this effort.

C. Justification:

(1) Control at LEO during construction is a critical phase because of the large aerodynamic forces and gravity gradient torques. The growth in size, inertia, and drag area requires a corresponding growth in control authority, and a probable distribution of control sensors and actuation. This study effort would provide solutions contributing to the viability of the SPS concept.

(2) Control with thrusting during the transfer from LEO to GEO involves problems due to attitude maneuvers, thrust interactions and time-varying gravity gradient and aerodynamic torques. In addition, if a low thrust (electric propulsion) system is used, solar collector pointing will probably be required. The complexities of this problem must be solved in order to increase confidence in the concept.

(3) Control of the SPS in GEO involves precision pointing of the antenna and maintaining a consistent orientation of the solar array toward the sun for long term operations. Concepts of

distributed sensing and control for the solar collector, and precision mechanical pointing and beam steering for the antenna must be devised and analyzed.

D. Technical Plan:

(1) Objectives

The principal objectives of this element of the SRT item are to produce preliminary specifications and a development plan for the technique for controlling an SPS during construction in LEO.

Technical Approach

(a) Assemble all pertinent data regarding SPS shape, mass characteristics, and structural characteristics during the span of the construction period.

(b) Analyze orientation requirements and establish construction altitudes.

(c) Synthesize and compare alternate control methods to meet the requirements.

(d) Simulate leading candidate alternate control methods and compare performance and control margins.

(e) Produce preliminary specifications and a development plan for the chosen method.

(2) Objectives

The principal objectives of this element are to derive a technique for attitude and trajectory control during transfer to GEO. Preliminary specifications and a development plan will be the major outputs of the study.

Technical Approach

(a) Analyze and optimize the orbit transfer mechanics for high (chemical propulsion) thrust and low (electrical propulsion) thrust injection.

(b) Apply constraints associated with realistic control of the SPS in the flight environment, and derive general thrust and actuation configurations for both high and low thrust injections.

(c) Compare both high and low thrust injections and choose one of the techniques.

(d) Synthesize a stability and control mechanization for the chosen injection method, and develop it to the degree suitable for stability analysis and simulation.

(e) Perform analysis and synthesis of mechanization of the control system and optimize the solution.

(3) Objectives

The principal objectives of this element of the SRT item are to derive optimized methods for attitude control of an SPS solar collector and microwave antenna for long term operations in GEO. The major products would be preliminary specifications and a development plan for the flight control system.

Technical Approach

(a) Derive and survey the orientation, pointing, and station keeping requirements for the SPS in GEO.

(b) Synthesize an optimum orientation control system for the solar array in terms of actuation and sensors located along the array, and devise orbit keeping technique.

(c) Synthesize a pointing control system for the microwave antenna and couple it with the solar collector orientation system.

(d) Analyze and synthesize the combined systems and optimize performance and response with failures.

(e) Produce preliminary specifications and development plans for SPS total flight control system.

E. Resource Requirements: Manpower and funding requirements are shown in Table 3.3-1. No specialized facilities are required.

MCDONNELL DOUGLAS

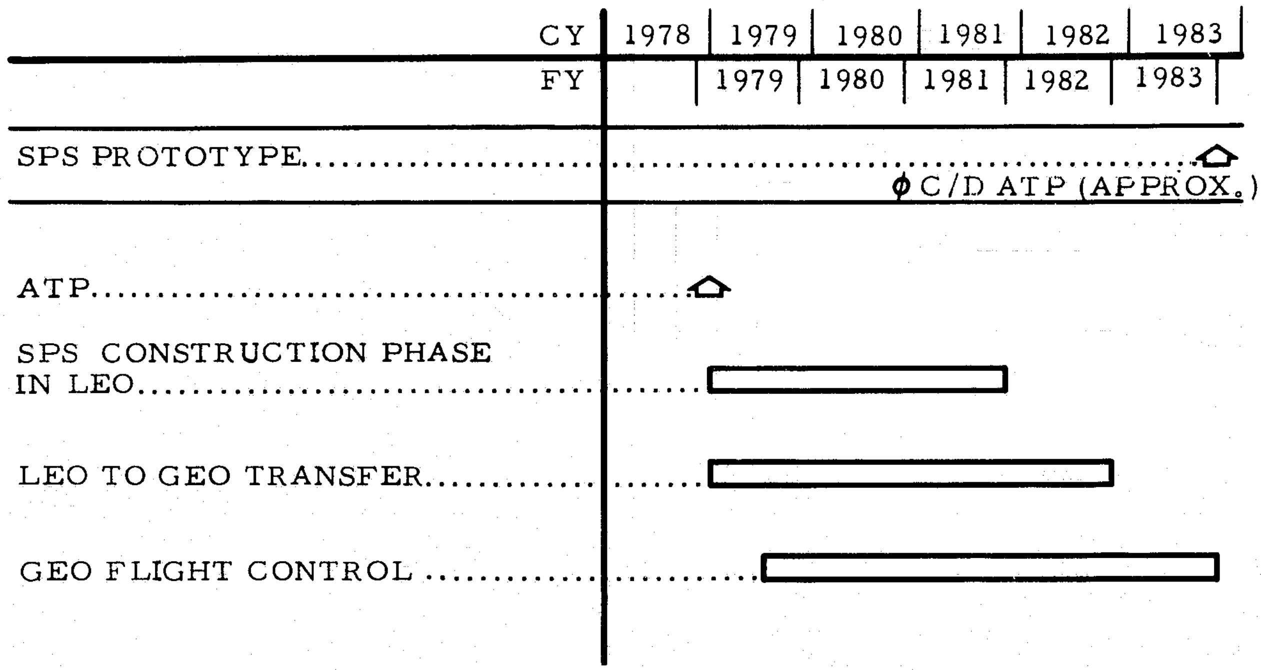
Table 3.3-1

Manpower and Funding Requirements

	FY1978	FY1979	FY1980	FY1981	FY1982	Totals
Manpower (man-yr)						
• SPS Construction in LEO	1	2	4	4	2	13
• SPS LEO-GEO Transfer	1	1	2	4	4	12
• SPS Flight Control in GEO	2	4	4	2	1	13
	4	7	10	10	7	38
Funding (including computer costs)						
• SPS Construction in LEO	\$90K	\$170K	\$350K	\$350K	\$170K	\$1130K
• SPS LEO-GEO Transfer	90K	90K	170K	350K	350K	1150K
• SPS Flight Control in GEO	170K	350K	350K	170K	90K	1130K
	\$350K	\$610K	\$870K	\$870K	\$610K	\$3310K

CR60

F. Target Schedule:



A. Title: RADIOMETER DESIGN DEVELOPMENT

B. Status: Small scale radiometers have been flown for some time. However, radiometer systems of the size, resolution (temperature and spatial) and tolerance requirements of the contemplated systems will require significant development.

C. Justification: In order to provide significant improvements in radiometry resolutions, large antennas with extremely high tolerance surfaces must be developed together with radiometry receiving systems having lower noise figures than presently available. The effort would be a follow-on to the 4m Shuttle Imaging Microwave System, a JPL program.

D. Technical Plan:

(1) Objectives

One objective of the work includes the selection and/or development of methods to assemble and/or deploy large scanning antennas with the requisite error tolerance. A second objective is to assure that an electronic scanning system can be built with a noise temperature sufficiently low to provide the temperature resolution required to discriminate the phenomena of interest. This latter objective may be the more difficult to achieve due to the long waveguides required to connect the feed system to the radiometer.

(2) Technical Approach

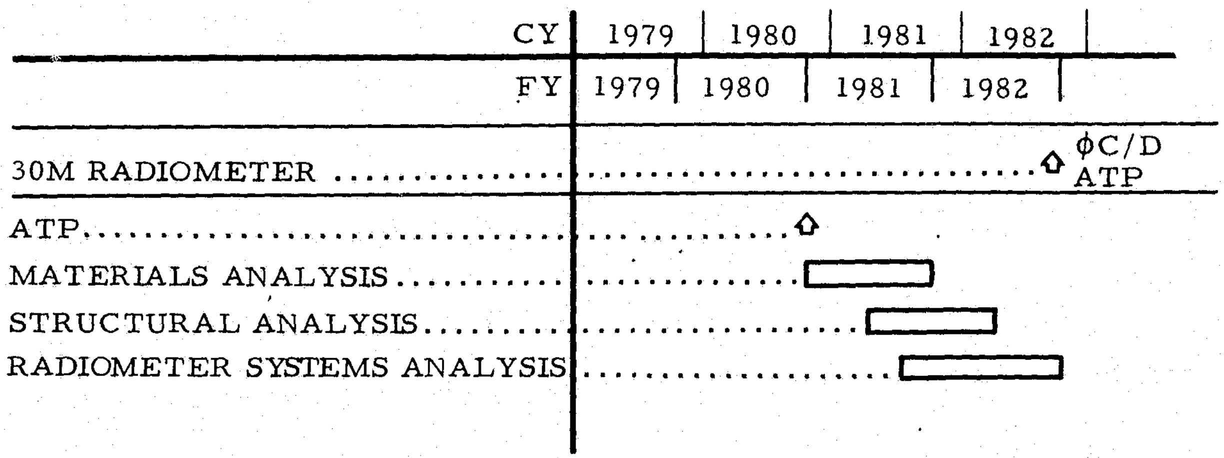
The proposed approach is to separate the two problems into respective structural/mechanical and radiometry system design feasibility tasks. (Separation of the two tasks would allow advantage to be taken of on-going research in materials and structures for other space applications.) The successful culmination of both would allow the inception of prototype feasibility demonstration models. For that reason this SRT is limited to concept feasibility and materials research only.

E. Resource Requirements:

	FY 81	FY 82	Totals
(1) Manpower (man-yr)	4	4	8
(2) Specialized Facilities	Materials Laboratory (existing)		
(3) Funding			
• direct labor	$320K	$320K	$640K
• equipment and material	40K	80K	120K
	$360K	$400K	$760K

F. Target Schedule:

CR60



A. <u>Title:</u> MULTI-BEAM LENS ANTENNA

B. <u>Status:</u> Multi-beam experimental transverse electromagnetic (TEM) or "bootlace" lenses have been developed and tested at lower frequencies. However, this effort must be essentially repeated for new antenna configurations and materials.

C. <u>Justification:</u> The antenna designs previously tested had spherical inner surfaces and planar outer surfaces. In order to provide reasonable Orbiter cargo bay packing densities, a planar surface on both sides is needed. In addition, metal has been used to date to hold the delay lines. It is desired to use a composite material such as graphite-epoxy, thereby reducing weight and improving thermal characteristics. Finally, tests performed to date have been on test articles with fewer than 100 elements. Larger scale test models are required using multiple feeds to ensure that the required electrical characteristics can be achieved.

D. <u>Technical Plan:</u>

(1) <u>Objectives</u>

There are two primary objectives of multi-beam lens R&T. The first is to develop a large communications system design which optimizes performance for a system tailored for transfer to orbit by the Shuttle and on-orbit assembly. The second objective is to perform sufficient simulation, modeling and testing of the design on the ground to demonstrate the achievement of technical objectives and minimize program risk. Secondary objectives include (1) the development of suitable lens materials, (2) the fabrication of lens components tailored to dimensions and tolerances required at the upper levels of the radio band which are compatible with on-orbit assembly methods, and (3) the demonstration of a working system. In conjunction with the lens, it will be necessary to develop and demonstrate the antenna feed-beam forming capability, and the switching and addressing required for total system operation.

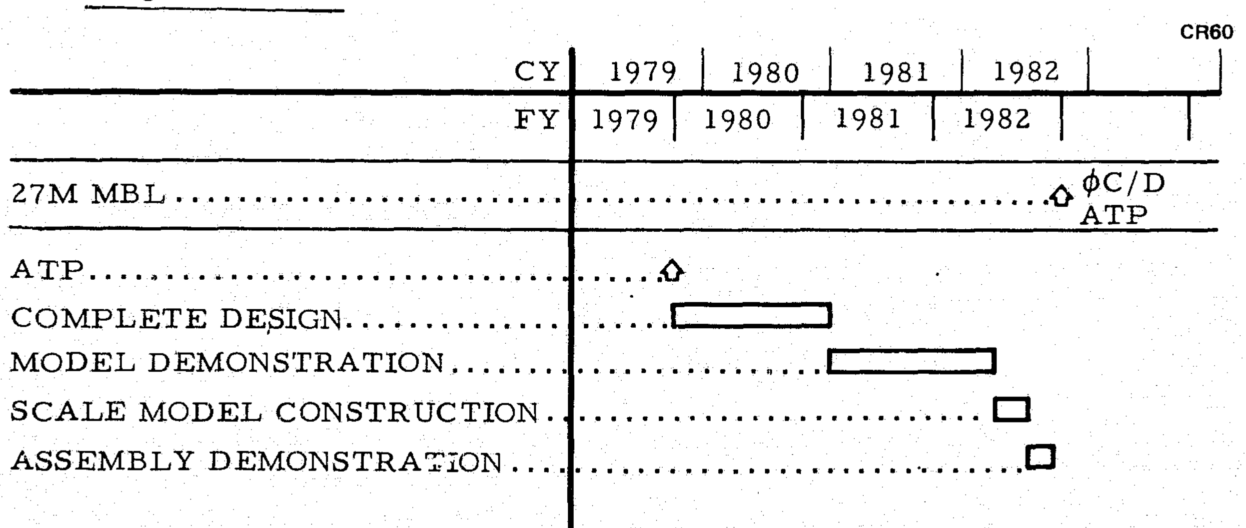
(2) Technical Approach

The immediate requirement is to establish the feasibility of a flat lens system. This will require that a model of the system be designed, constructed and tested. Following successful demonstration of the concept, work should proceed simultaneously on the switching and control aspects as well as the development of structural materials and joining assembly methods. A full scale structural model of a section of the antenna should then be fabricated and joining techniques demonstrated in a simulated zero-g environment.

E. Resources Requirements:

	FY 80	FY 81	FY 82	Totals
(1) Manpower (man-yr)	3	5	6	14
(2) Facilities				
• antenna test range		X	X	
• neutral buoyancy tank			X	
• materials laboratory	X	X	X	
(3) Funding				
• direct labor	$240K	$400K	$480K	$1120K
• equipment and materials	40K	120K	240K	400K
	$280K	$520K	$720K	$1240K

F. Target Schedule:



A. Title: SPACE PROCESSING ENVIRONMENTAL IMPACTS

B. Status: An accurate description of the environmental parameters which are critical to materials processing in space is presently unavailable. A systematic review in coordination with the principal investigators is needed to define the critical parameters, the expected environment, and the means to measure it.

C. Justification: Materials science and technology investigations and the subsequent commercial space processing missions will require a precise definition and description of the local orbit environment. Data on the expected environment and measurements of the environment actually encountered are crucial to the analysis and understanding of the results of tests and to planning for future tests. Specific environmental data are required for such parameters as (1) local g level, (2) shock and vibration, (3) temperature, (4) acoustic level, (5) atmospheric composition and conditions, (6) electromagnetic radiation, (7) particulate radiation, (8) microbal activity, (9) electrical power transients, (10) illumination, and (11) crew interfaces. Timeline histories will be required for many of the parameters.

Much of the required data can be made available from interface control engineering data and instrumentation. However, for the purposes of materials processing investigations, the accuracy of the predicted versus the experienced environment is not satisfactorily known.

D. Technical Plan:

(1) Objectives

The main objective of this SRT item is to determine in quantitative terms the environmental parameters which are important to material processing in space. Once determined, means need to be identified for forecasting the environment as well as measuring it during spaceflight. For those parameters that are determined to be critical to space processing, control measures need to be incorporated in the basic design of the processing modules and/or the SCB. Since both functional and operational interfaces are involved, a method of evaluating the adequacy of the control mechanisms should be devised. One such method would be a computer simulation of affected space processing operations.

(2) Technical Approach

(a) Survey space processing activity (SPA) principal investigators to identify the environmental parameters critical to their processes.

(b) Develop environmental control requirements in terms of parameters to be controlled, the expected acceptable level for each parameter, and the preferred methods for measurement and instrumentation.

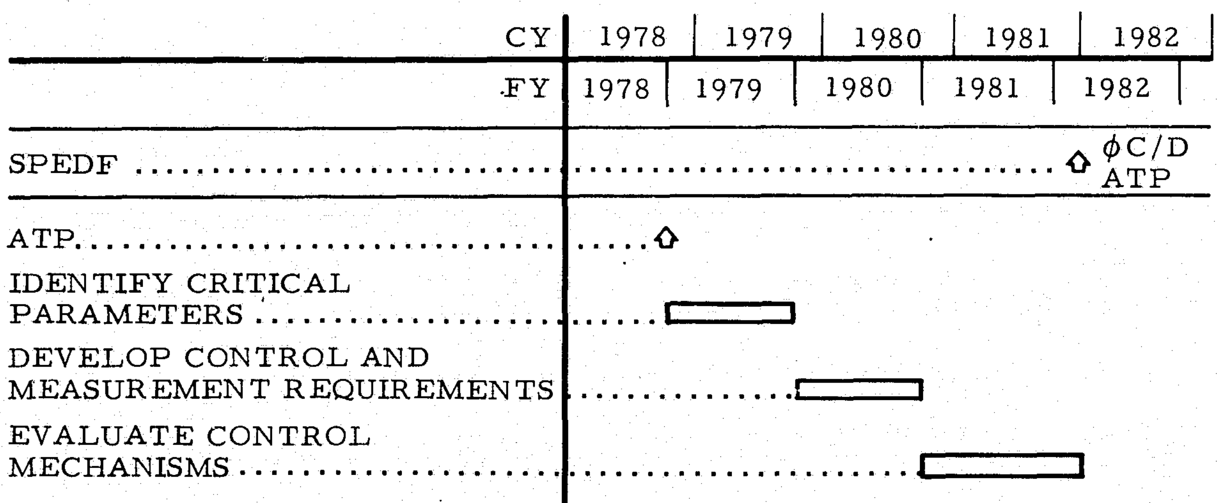
(c) Perform analyses and simulations to evaluate functional and operational interface control mechanisms.

E. Resource Requirements:

	FY 79	FY 80	FY 81	Totals
(1) Manpower (man-yr)	2	4	4	10
(2) Specialized facilities		none required		
(3) Funding				
• direct labor[1]	$170K	$330K	$330K	$830K

F. Target Schedule:

CR60



[1] Includes computer costs